Eleventh International Dryland Development Conference

Global Climate Change and its Impact on Food & Energy Security in the Drylands

18-21 March 2013, Beijing, China

Proceedings

International Dryland Development Commission

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Eleventh International Dryland Development Conference

Global Climate Change and its Impact on Food & Energy Security in the Drylands

Organized by
International Dryland Development Commission (IDDC)

Hosted by
The Chinese Academy of Sciences (CAS)
Cold and the Arid Regions Environmental and Engineering Research Institute (CAREERI), CAS, China

18-21 March 2013, Beijing, China

Proceedings

Editors

Adel El-Beltagy, Wang Tao and Mohan C. Saxena

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International Dryland Development Commission (IDDC)

The International Dryland Development Commission (IDDC) is an autonomous nongovernmental nonprofit organization established in 1987 by the individuals and institutions interested in and concerned about the sustainable development of dry areas. It is promoting all aspects of dryland studies by fostering cooperation, collaboration and networking between various international, regional and national organizations. One of the important *modus operandi* of the networking of IDDC has been to hold a major scientific conference every two to three years to provide opportunity to participants from around the world to exchange research results and experiences in dryland development and combating desertification. In pursuance of this objective the IDDC has organized in the past following ten international conferences held in countries that have large dryland areas:

1. First International Conference on Desert Development: *Application of Science and Technology for Desert Development*, Cairo, Egypt, 1978.
2. Second International Conference on Desert Development: *Desert Development Systems – Technologies for Desert Agriculture, Energy and Communities*, Cairo, Egypt, 1987.
3. Third International Conference on Desert Development, Beijing, China, 1990
4. Fourth International Conference on Desert Development: *Sustainable Development for our Common Future*, Mexico City, Mexico, 1993.
5. Fifth International Conference on Desert Development: *Desert Development -The Endless Frontier*, Lubbock, Texas, 1996.
6. Sixth International Dryland Development Conference: *Desert Development: Challenges in the New Millennium*, Cairo, Egypt, 1999.
7. Seventh International Dryland Development Conference: *Sustainable Development and Management of Drylands in the 21th Century*, Tehran, Iran, 2003.
8. Eighth International Dryland Development Conference: *Human and Nature working together for Sustainable Development of Drylands*, Beijing, China, 2006.
9. Ninth International Conference on Dryland Development: *Sustainable Development in the Drylands – Meeting the Challenge of Global Climate Change*, Bibliotheca Alexandrina, Alexandria, Egypt, 2008.
10. Tenth International Conference on Development of Drylands - *Meeting the Challenge of Sustainable Development in Drylands under Changing Climate - Moving from Global to Local*, Cairo, Egypt, 2010.

Partners / Co-sponsors of 11th Conference

- Association of Agricultural Research Institutions in the Near East and north Africa (AARINENA)
- Arid Land Research Center (ALRC), Tottori University, Japan
- Chinese Academy of Sciences (CAS), China
- China Elion Green Foundation (CEGF)
- Desert Research Institute (DRI), Nevada, USA
- International Center for Agricultural Research in the Dry Areas (ICARDA)
- Japanese International Research Center for Agricultural Sciences (JIRCAS)
- Japanese International Cooperation Agency (JICA)
- National Natural Science Foundation of China (NSFC)
- United Nations University-Institute for Water, Environment and Health (UNU-INWEH)

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Foreword

The Intergovernmental Panel on Climate Change (IPCC), using different models, has reaffirmed that the climate change is occurring globally and it is going to have serious impacts on agriculture and natural resources in the dry areas, particularly in the West Asia and North Africa region. Much of the predictions of impacts have, however, been based on global assessment. It is well known that the global assessment glosses over the regional and the regional over the local variations in the magnitude and direction of impacts. Precise information on local and regional levels is, therefore, crucial for developing appropriate strategies to cope with the adverse impacts through required adaptation and mitigation measures.

Recognizing the limitation of global assessment of climate changes for devising appropriate coping measures, the International Dryland Development Commission organized its tenth international conference – *Moving from Global to Local* – in Cairo, Egypt in 2010, proving a platform for sharing and analyzing information on the need and methods and some results of moving the impact assessment from global to local. The deliberations also highlighted the urgency of taking action to tackle the problems associated with the adverse impacts of rising temperatures, changing cropping seasons, increasing variability in the magnitude and distribution of rainfall, and, in some parts, increase in the level of sea water, on food production and food security in the dry areas. Rise in the food prices, partly because of diversion of food crops to produce biofuel – as a strategy to reduce the use of fossil fuel for mitigating climate change – and the prices of energy is further accentuating food insecurity in the dry areas and adversely affecting the livelihood of the dryland communities. Hence, there is an urgent need for more precise assessment of adverse impacts of climate change on the nexus of food and energy security and for developing interventions to cope with the problem. Intensive knowledge is required to increase the adaptive capacity and minimize vulnerability in the dry areas. It is in this background that the International Dryland Development Commission organized this Eleventh International Conference on Dryland Development in Beijing, China, under the title *Global Climate Change and its Impact on Food and Energy Security in the Dry areas.*

A total of 26 plenary and more than 100 oral and poster presentations were made by scientists, development experts, and policy makers from different countries and organizations on eight themes relevant to the subject. A panel of experts conducted in depth analysis and led general discussion on the strategies that need to be developed for increasing food and energy security in the dry areas. Based on these deliberations, the participants developed a *Beijing Declaration* to inform all stakeholders about the urgency and direction of the course of action. This volume contains most of the information emanating from these deliberations. We hope that it will be of interest to the scientific community, development agencies, policy makers and other stakeholders interested in the food and energy security and the sustainable development of drylands in the face of changing climates.

Adel El-Beltagy
Wang Tao
Mohan C. Saxena
Editors

Inaugural Session Presentations

Opening Statement by the Chair of International Dryland Development Commission (IDDC) Prof. Adel El-Beltagy:

On behalf of the International Dryland Development Commission (IDDC), it is a great pleasure for me to welcome you all to the 11th International Conference on Dryland Development at the Friendship Hotel of this beautiful city of Beijing. This is not the first time that we are meeting here and we will like to thank our esteemed hosts, the Chinese Academy of Sciences (CAS) and Cold and the Arid Regions Environmental and Engineering Research Institute (CAREERI) of CAS, for making this possible. This shows the commitment of CAS to the sustainable development of drylands and to controlling and reversing the process of desertification. We are indeed greatly indebted to Prof. Chunli Bai, President of CAS, for his enthusiastic support to this Conference ever since the idea was mooted to hold the Conference in Beijing.

Although, most of you might be familiar with the International Dryland Development Commission (IDDC), allow me to take a few minutes to once again reiterate the mission and objectives of IDDC. It is an autonomous nongovernmental nonprofit organization established in 1987 by the individuals and institutions interested in and concerned about the sustainable development of dry areas. It is promoting all aspects of dryland studies by fostering cooperation, collaboration and networking between various international, regional and national organizations. One of the important elements of the *modus operandi* of the networking of IDDC has been to organize a major scientific conference every two to three years to provide opportunity to participants from around the world to exchange research results and experiences in dryland development and combating desertification. In pursuance of this objective the IDDC has organized in the past ten international conferences held in the countries that have large dryland areas, i.e. China, Egypt, Iran, Mexico and USA.

The drylands account for nearly 40% of the global land area. Constrained by the shortage of water they represent a very fragile ecosystem. Yet they provide livelihood to nearly a billion people living there. A majority of these people being poor, they tend to adopt practices that are exploitive in nature accentuating the degradation of the natural resources of land, water and biodiversity. The negative effects of these anthropogenic factors are getting further accentuated by the global climate change. Strategies, therefore, are needed to stem this degradation, which is viciously linked to poverty and insecure livelihoods of dryland communities, particularly in the developing countries which are most vulnerable to the adverse effects of global climate change. That is the reason why the IDDC had laid special attention to the theme of Global Climate Change in its past two conferences. As you would recollect, the Ninth International Conference held in 2008 had the theme "Sustainable Development in the Dry Lands - Meeting the Challenge of Global Climate Change" and the Tenth International Conference organized in 2010 had the theme "Meeting the Challenge of Sustainable Development in Drylands under Changing Climate– Moving from Global to Local". This, Eleventh International Conference deals with the theme "Global Climate Change and its Impact on Food & Energy Security in the Drylands" as ensuring security of food and energy for growing population in the future is strongly challenged by the need for actions that would lead to adaptation to current, and mitigation of future, climate changes. The deliberations in the next few days should help us identify strategic frame work that may enable the dryland stakeholders to face this challenge.

The Conference is happening because of the commitment and support of our hosts and cosponsors which is gratefully acknowledged. We are fortunate to have their representatives on the dais and I will now like to invite them to make their statements. But before I do that, I will like to thank you all for your participation in the Conference and for your commitment to the IDDC.

Statement by the Representative of the Host Country, Prof. Tao Wang, President of Lanzhou Branch of the Chinese Academy of Sciences (CAS):

On behalf of the Chinese Academy of Sciences and the Cold and the Arid Regions Environmental and Engineering Research Institute (CAREERI), as well as, on my own behalf, it is a great pleasure for me to welcome you all to this Eleventh International Dryland Development Conference in our capital city, Beijing. I will also like to convey to you the words of warm welcome from the President of CAS, Prof. Bai Chunli, who was going to chair this Inaugural Session but has been unable to do so because of some unavoidable reasons. We are thankful to the International Dryland Development Commission for accepting our invitation to host this conference.

Dryland development and desertification control are topics of great economic and social importance for the Peoples Republic of China and their significance has gained further importance in the face of climate changes being faced by the country. That is the reason as to why scientific institutions under the auspices of the Chinese Academy of Sciences and various development agencies of the country, with full support of central and provincial governments, have been devoting considerable efforts in developing viable interventions and strategies not only for sustainable development of dry areas, but also for preventing any new desertification and recovering the lands already desertified in the past. Considerable success has been achieved in the past and you will get a glimpse of this from the presentations to be made by Chinese colleagues in this Conference.

The Local Organizing Committee has made all efforts to ensure that your participation in the conference is productive and your stay here in the Friendship Hotel is comfortable. Please do not hesitate to contact the committee members if you need any further assistance. I wish you a pleasant stay and a very successful conference.

Statements by Co-sponsors:

1. AARINENA - *Fawzi Al-Sheyab, President of AARINENA and DG of National Center for Agricultural Research and extension (NCARE), Jordan*

It gives me a great pleasure to address this meeting on behalf of the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA). ARRINENA represents a vast area, broadly defined as West Asia and North Africa (WANA), that extends from Morocco in the West to Afghanistan and Pakistan in the East, and from Turkey in the north to the Arabian Peninsula in the South. This area includes the largest dryland region in the world with its natural resources under great threat of degradation due to the climate change and socio-economic factors. This area is characterized by an erratic rainfall and only 14% of the land area is suitable for rainfed cropping and much of the rest suitable only for extensive land use practices.

Despite its dryness, WANA is an important center of plant biodiversity. Many of the world's major food crops, pasture species, herbs and medicinal plants originated in the region. The genetic resources here harbor many genes for drought and salinity resistance. However, WANA has one of the fastest population growth rate in the world. The population is projected to grow from 200 million in 1960's to about 930 million by 2020. To feed this rapidly expanding population has been a major strategic concern of almost all the countries in the region. Despite heavy public and private development investments, the land and water resources available for agricultural production are very limited and the production cannot meet the growing food demand, and the regional food self-sufficiency ratio has continued to fall every year. This has been triggering increase in the price of food and raising the cost of living in the region. The farmers and pastoralists have responded to these changing demographic and economic circumstances by seeking to intensify production through greater exploitation of their limited resource base of soil, water and natural vegetation which is leading to degradation of these resources.

To ensure reversal of degradation of drylands, increase land productivity, and permit adaptation to climate change, we need to apply a range of strategies - developing more appropriate production techniques, socio-economic institutional arrangements, and policy actions. Methods of management of the land and its vegetative cover that are technically feasible, socially acceptable and sustainable will be needed.

AARINENA is trying to help its members to improve their capacity and help them develop their national strategy for adaptation to climate change. Accordingly, AARINENA organized the 12th General Conference in Kuwait that was devoted to adaptation to climate change in the WANA region. It is also working with the Global Forum for Agriculture Research and Development (GFAR) on establishing the Interim Secretariat on Climate Change for the region. By co-sponsoring the 11th ICDD, AARINENA is hoping to encourage development of good practices that would promote developing strategies for climate change adaptation and improving land productivity.

I wish the Conference all the success.

2. ALRC, JIRCAS & JICA – *Atsushi Tsunekawa, Director of ALRC, Tottori University, Japan*

On behalf of the Arid Land Research Center (ALRC), and also JICA and JIRCAS, co-sponsors from Japan, I would like to express sincere gratitude to Prof. Adel El-Beltagy, Chair of International Dryland Development Commission, for organizing this Conference. A series of this Conference was started in 1978, 35 years ago as International Conference on Applications of Science and Technology for Desert Development. During last three decades, the Conference has grown and become a truly international platform for discussing the science and technology for dryland development. The excellent foresight and strong leadership of Prof. El-Beltagy in this regard should be admired.

I would also like to express my appreciation to Prof. Wang Tao, Chair of Local Organizing Committee, for arranging this conference so perfectly. Thanks to him and his colleagues, we could gather together here again. Seven years ago, in 2006, it was my first time to attend this

Conference, which was also held in Beijing. As a participant from Japan, I am feeling happy, because we are sharing common environmental problems with China such as Asian dust issue. For this Conference, I tried to encourage young researchers of my University, including graduate students, to participate. I hope those young researchers can exchange ideas with Chinese and other foreign participants, foster linkages and deepen their friendship.

Now, let me briefly introduce our Arid Land Research Center of Tottori University. ALRC was established in 1990. We are playing a role in organizing joint research with several Japanese researchers, not only from Tottori University but also other universities and research institutes, in the field of dryland science as a “Joint Usage/Research Center”. As a Center of Excellence in Dryland Science it aims to tackle issues related to drylands, such as desertification and drought, and promote studies for maintaining and improving sustainability of nature-society systems in drylands.

As you know, we have no arid land in Japan, although the name of our Center is Arid Land Research Center. So, we are always making our best efforts to carry out collaborative researche with foreign research institutes. For example, with the Desert Research Institute (DRI) researchers our colleagues are studying aeolian dust problem; with UNU, we are conducting capacity building program, Joint Master’s Degree Programme on Integrated Drylands Management with institutes such as ICARDA, CAREERI and IRA. With ICARDA, we are jointly conducting molecular breeding project focusing on wheat, and also several capacity building projects. With CAREERI, China, in addition to the MS Program, we are jointly studying about Asian dust issue which is common international environmental problem among the East Asian countries. Also in China, we have been carrying out collaborative research project with Soil and Water Conservation Institute located in Yangling, focusing on Chinese Loess Plateau. The achievements made in this joint program are being published in a book titled “Restoration and Development of Degraded Loess Plateau, China”. This book will be published by Springer this year.

Without the support of the partners, our Center cannot conduct arid land research at all. So, using this opportunity, I’d like to acknowledge my appreciation of our partners and researchers belonging to the partner institutions.

Now, let me introduce JICA (Japan International Cooperation Agency), which is a part of Japan’s official development assistance effort, with a role in providing technical cooperation, capital grants and yen loans. Major aid modalities of JICA are: 1) technical assistance programs/projects for capacity and institutional development, 2) feasibility studies and master plans, and 3) dispatch of specialists. Its activities are closely related with this Conference through its thematic issues such as agricultural and rural development, poverty reduction, water resources, disaster management, natural environment conservation, etc.

JIRCAS (Japan International Research Center for Agricultural Sciences) is another partner of the ICDD. It was established in 1993, through the reorganization of its predecessor, the Tropical Agriculture Research Center (TARC), in order to include overseas forestry and fisheries research in its mandate. It was again restructured in April 2001 as an Incorporated Administrative Agency under the Ministry of Agriculture, Forestry and Fisheries. JIRCAS is the sole national institute that undertakes comprehensive research on agriculture, forestry and fisheries technology in developing areas of tropical and subtropical regions, aimed at providing solutions to international food supply and environmental problems through technology development.

Finally, the theme of this conference is focusing on "Global Climate Change and its Impact on Food and Energy Security in the Drylands". This is very important topic, because we are facing common problems caused by climate change. In this sense, we have to combat such a difficult problem by uniting our strength. My expectation from this Conference is that we can renew our friendship and unite our strength to tackle the problem constraining better future of drylands.

Thank you for your attention.

3. China Elion Green Foundation (CEGF) – *Wang Wenbiao, Standing Member of China CPPCC and Chairman of Elion Foundation;* *(note: the statement was delivered after showing a video on greening a part of Kubuki Desert)*

I was born in Kubuqi Desert which you just saw in the short video. Over the past years I have been searching persistently for an answer to the question as to how we can change the fate of the children, like that of Sun Yuan in the short video, who call desert their home. I am going to share a true story here with you. During the first session of the United Nations Human Development Summit in 1992, a 12year-old Canadian girl named Sever Suzuki raised three questions and one of them touched me deeply. She asked: "Adults, can you turn desert back into forest"? Twenty years later, it was also at the Rio+20 Summit in 2012, I brought with me the answer to the question of the little girl: Yes, we can. With the support of the Chinese Government, together with my Elion Resources Group, we have turned more than 10,000 square kilometer desert land into oasis.

I started my battle against desert 25 years ago. Together with my Elion Resources Group, I was able to get in 25 years more than 5000 square kilometers of desert land afforested, that is about one 1/7000 of the desertified area of the earth. At the same time, more than 30 billion RMB worth of ecological value was generated. At present, there is not only oasis in the desert, there is even signs of soil reappearing as also some flora and fauna (such as poplar, wild foxes and wild rabbits) that disappeared long ago. In the context of desert green-economy, we have also invested tens of billions RMB in the development of desert industries including clean energy, pharmaceutical industry based on natural products, modern agriculture, etc. Combating draught and meeting the challenge of the desert is the most arduous and difficult task of mankind. In order to make breakthrough in this area, one must rely on technological innovation as well as other essential elements such as persistence, determination and strong will.

We have tried many different kinds of drought resistant plants that could survive in desert and have used traditional ways of experimenting with them - trial and error. We tried more than hundred different kinds of plants and spared no effort or money to import sand-growing plants from abroad. We identified some 20 different kinds of plants that are sand resistant and of good economical value. *Salix* for example, is not only sand resistant but can also be used for feed and energy industry. We invented a new "water-washed planting technique" which reduced the cost of mass planting, and increased survival rate. Using this new technique, a team of two persons can plant more than 20 *mu* (50 *mu* = 1 ha) of area, which is about 30 times more efficient than the traditional planting using spade. The cost per mu has been lowered by about 2000 RMB and the survival rate has increased to 90%. The technique also made it possible to plant saplings on high sand dunes. While only 50 to 100 square kilometers per year could be planted in the past using traditional method, more than thousand square kilometers are planted each year at present.

I hold in high esteem the scientific community represented by you that works diligently in desert and drought-affected areas, because with one more of your innovation, there would be one more piece of green civilization on earth. China's eco-civilization has become its basic national policy, and green economy is becoming a common demand of mankind. I believe that without technological innovation, there shall be no prosperity of green economy, not to mention about the realization of eco-civilization. This is especially important for desertified areas with hostile natural conditions.

There are billions of people on earth who still suffer from hunger because of drought in the desert. There are still billions of *mu* of desert land that should be improved for its ecological environment. I sincerely wish that all scientists that are present here could work together with us to promote China's ecological civilization and to contribute to the green civilization of the world.

In closing, in my capacity as Secretary General of Kubuqi International Desert Forum, I would like to take this opportunity to extend my invitation to all present here to attend the Fourth Kubuqi International Forum which is going to take place in July/August 2013 and make contributions to the development of desert green economy.

4. DRI – *Stephen G. Wells, Director of Desert Research Institute (DRI), USA*

I will like to join my colleagues on the table in extending a warm welcome to you all to this 11th International Dryland Development Conference. I will also like to express my thanks to Dr. Adel El Beltagy for his guidance and steady hand on the helm as the IDDC Chair. The local organizing committee under the leadership of Dr. Wang Tao, President of the Lanzhou Branch of the CAS, has made excellent arrangements for our deliberations, which are highly appreciated.

There is an unprecedented global nexus that faces humanity. It is the inextricable linkage among water, energy, food security and climate. I am pleased to see that the 11th ICDD conference's theme focuses on this nexus, and can only hope that our voices and scientific findings from this conference will be heard and applied to help address worldwide hunger and alleviate the deaths of ~6 million children under the age of 5 per year.

We all know that the challenge of feeding the global community is urgent and that the cost of doing nothing is incomprehensible. Global food prices are the highest in decades, and yet 1 billion people live on a dollar or less a day. The FAO has estimated that the cost of under-nutrition in mother and child far exceeds $30 billion per year and in some regions such as Central America and the Dominican Republic under-nutrition costs are equivalent to 11 percent of a country's GDP and a 90% loss in productivity and income. If measured over a generation's life time, such loss in productivity and income may range between $500 billion to $1 trillion US dollars.

When combined with climate change, the situation worsens in ways that is difficult to fathom. Oxfam International has reported that by 2015, climate-related disasters will affect over 50% more people annually than the previous decade. This includes the United States, where climate change unfortunately remains a politically debated concept and not a scientific reality in many peoples' minds. Significant changes in the amount of snow accumulation, significantly earlier spring snow melt, a paucity of long-term storage, growing demands from urban regions, and the exhaustion of relic groundwater sources are limiting our ability to use irrigation to offset global climate change in drylands around the world.

The combination of improper land use such as inappropriate grazing techniques, sub marginal cropping practices, over irrigating, and other activities become exacerbated with the likely consequences of climate change. New approaches and creative solutions to achieve sustainable agriculture are critical in the face of what is most likely to occur becomes increasingly difficult and complex situation. Integrated solutions are required. The efforts of international exchanges such as this conference help to link work done by farmers, policy makers, and research organizations through effective communication strategies.

One significant effort has been underway for some time within the Desert Research Center of Egypt through its Gene Bank in Sinai to develop drought and salt tolerant species. Unfortunately, recent events that followed our last ICDD in Cairo have seriously set back this visionary effort. Other efforts, such as those being accomplished through the ALRC of Japan, and the CAREERI of China, are focusing on efforts to restore degraded lands, to stabilize mobile sand, to develop drought early warning systems, are achieving positive results.

Meeting the challenges of this "global nexus" will require the type of sound science such as the type being presented at this meeting in combination with (a) systematic long-term planning: (b) adaptive management based on integrating policy making, economics and politics with the solid science; and (c) effectively communicating our scientific endeavors in a format that is understandable and impactful.

I am grateful for this conference to help us in this endeavor. Thank you.

5. ICARDA – *Mahmoud Solh, Director General (* *presented by Michael Baum)*

Welcome to the 11th International Conference on Dryland Development. With the ever-increasing evidence of changes in climate patterns the topic of this conference is becoming increasingly important. I would like to summarize for you the factors that I believe are the key to make a difference to the development of drylands.

First and foremost, political will and support are essential to place water, agriculture and food security as a priority for investment at the national level. Policies need to change from reactive to proactive, to prevent further degradation of drylands. Food production systems need to change from subsistence farming to the market production economic model. Water use needs to refocus from maximizing yield to maximizing water productivity and income. Land use needs to change from land/soil degradation to soil conservation and enrichment. For institutions, a shift in thinking is needed - away from top down approaches to approaches that empower communities.

To support these changes, we need to invest more in science, technology and agricultural research and development. Drylands need to be developed - in high potential areas - through the sustainable intensification of production systems. While for marginal lands, the focus should be on a resilient production system and ecosystem approach. Agricultural extension activities need to be strengthened and effective technology transfer mechanisms developed within the countries. We also need increased investment in capacity development and support to institutions.

This action list may seem daunting. And yes there is much work to be done. But we see good news. From the perspective of our work at ICARDA, learned over three decades of supporting countries to improve their food security situations – many of the solutions exist. They are being tried and tested by countries and development partners. So today's important and urgent work is to understand how to best scale these up and mobilize our efforts to make this happen.

I wish you a successful conference.

6. United Nations University (UNU) – *Zafar Adeel, Director, UNU-INWEH*

Good Morning! It is a great privilege to offer my warm welcome to you to this important conference. I bring you the warmest greetings from Dr. David Malone, UN Under-Secretary-General and Rector of UNU. He offers his best wishes but is unable to participate in the conference; he has quite recently taken charge as UNU Rector and is quite busy in the transition process. The commitment of UNU to drylands, however, remains very firm. We are committed to contributing to capacity development in drylands, enhancing knowledge to achieve solutions and creating bridges between science and policy. I re-affirm on behalf of UNU our support for the IDDC conferences, given their unique contribution to the science and solutions for drylands.

Let me also take a few moments to highlight the work that UNU is undertaking for drylands. I will mention three key initiatives that UNU has been engaged in over a number of years. The first one is an international Master's Degree programme that started with Tunisia at IRA and China at the Chinese Academy of Sciences, and which brings together graduate students from partner institutions to one location for sharing ideas. The list of partners has grown in the recent years to include ICARDA, Tottori University, CIHAEM and the Global Mechanism of UNCCD – it is a privilege that many of these partner as sitting at the table today. This programme has made major contributions to capacity development in drylands. The second initiative is called Economics of Land Degradation, which is a global study that aims to produce a final report much like the "Stern Report" for climate change. The objective is to highlight the worldwide costs related to land degradation and to underline the benefits of adopting sustainable land management approaches. The third initiative is the support that UNU provides to the UN Convention to Combat Desertification under an agreement that was signed four years ago. UNU was part of the consortium that had organized the first scientific conference for UNCCD and is now actively engaged in the second conference this year.

I would like to mention some key points that are important in the context of this conference. The cross linkage of food and energy security with water security in drylands is very important and is a matter of survival for drylands countries. But this linkage is also very timely because it plugs right into the global development agenda, which is being formulated to take effect after 2015 when the MDGs will conclude. The focus on water, food and energy security is an approach that is easily understandable in political and policy domains. Let us make sure that we get the message right.

I look forward to interesting and productive discussions on these topics during the conference. Thank you very much for your attention.

Inaugural Address

Prof. Bai Chunli

President of Chinese Academy of Sciences (CAS) & President of the Academy of Sciences for the Developing World (TWAS)

Good morning Ladies and Gentlemen!

It is a great pleasure and honor for us that the International Dryland Development Commission has given repeated opportunities to the Chinese Academy of Sciences to host the International Dryland Development Conferences (IDDC). The Academy hosted the 2nd and 8th IDDC in 1990 and 2006, respectively, and is now having again the pleasure of hosting the 11th IDDC in the Friendship Hotel, Beijing.

On behalf of the Chinese Academy of Sciences and on my personal behalf, I will like to warmly welcome you all to Beijing and participate in this 11th International Dryland Development Conference.

I met Prof. Adel EI-Beltagy, Chair of IDDC, in Tianjin, China last September during the Conference of Academy of Sciences for the Developing World (TWAS) and would like to thank him very much for his great contribution to that Conference. When Prof. Adel EI-Beltagy informed me at that time that the 11th IDDC will be held in Beijing this March, I was very happy and I promised to Prof. Beltagy that the CAS will provide full support to the Conference. All of you are witnessing that the Conference is actually happening now here and I have the privilege of formally opening the 11th IDDC. I would like to thank Prof. El-Beltagy, the Chair of ICDD, the Executive Secretary of ICDD, Dr. Mohan Saxena, and all the Members of the Board of the IDDC, and also you all as the participants of the Conference, for your efforts and contributions which make the 11th IDDC possible.

As you might know, the Chinese Academy of Sciences (CAS) was founded in Beijing on 1 November 1949, one month after the founding of the Peoples' Republic of China.

In the early days, the CAS was mandated as the key force of the new China's scientific research system, undertaking missions of defining scientific research orientations, restructuring its research institutions, encouraging and helping overseas Chinese scientists to return home, training and properly positioning the professionals on appropriate positions, outlining strategies for the nation's future scientific and technological development and, through these efforts, contribute to the national economic and social development. Since China adopted the process of reform and opening-up policy in the late 1970's, the CAS has been devoting itself into the reform and innovation for development, as a major driving force for transforming the national scientific and technological system and rejuvenating country's hi-tech industry, in the wake of the science and technology revolution unfolding in the World. The CAS, at the present is facing a new era of development. It is now targeting at the national strategic needs and world frontiers of science, striving to accomplish world-class standards in scientific research and to continuously make fundamental, strategic and forward-looking contributions to national economic construction, security and sustainable social development.

As the nation's highest academic institution in natural sciences and its supreme scientific and technological advisory body, and national comprehensive research and development center in natural sciences, it consists of several academic divisions and various component institutions.

At present, there are six academic divisions, functioning as the national scientific think-tank, providing advisory and appraisal services on issues stemming from the national economy, social development and S&T progress. Today's CAS has 12 branch offices, more than 120 institutes and 100 national key laboratories and national engineering research centers, and about 1,000 field stations throughout the country. Its staff strength exceeds 50,000 people.

In 1998, with the approval of the Chinese Government, the CAS launched the Pilot Project of the Knowledge Innovation Program (PPKIP) in an effort to build China's national innovation system. Since then, the CAS has made a series of major scientific breakthroughs in basic and cutting-edge research, bio-medical sciences, strategic high-technology, and research on sustainable development, thus making important contributions to China's economic development, social progress and national security.

For more than 60 years in the past, the CAS had paid major attention to the earth sciences, ecology, environmental sciences and regional sustainable development in the drylands, especially the Global Climate Change and its impact on food and energy security in the drylands of China, where the problem of land degradation/desertification is very serious. There were some encouraging results accomplished by the scientists of CAS in this area and they would like to share these results with you in this Conference.

The world development requires us to enhance our scientific innovation capability. The CAS aims to build itself into an organization with "first-class achievements, first-class benefits, first-class management and first-class talents" and into one that strives to reform and innovate for harmonious development, thus enabling it to continue making major fundamental, strategic and forward-looking contributions to China's economic development, national security and sustainable social development.

I would like to take this opportunity to congratulate you for your initiative to hold the 11th IDDC and tackle the theme which is becoming of increasing importance in the face of global changes. I am confident that your deliberations will be very successful and full of achievement. I wish you a very fruitful and enjoyable stay in China.

Thank you very much, once again, for your participation in the Conference which now I declare open.

Plenary Session Presentations

Plenary Session 1

People-centered sustainable dry area food and energy security in the face of climate change

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Abstract

Recognizing the growing importance and impact of climate change on food production, the International Dryland Development Commission (IDDC) has emphasized its implications on the livelihoods of the inhabitants in the dry areas in its last two international conferences as well as in this 11th Conference. The close linkage of food production and energy security with climate change makes it imperative to pay greater attention to the complex interactions in this relationship, which, if left unmanaged, will have serious negative implications on the livelihoods of the inhabitants of the dry areas, especially in the developing countries. Increasing fuel and food prices are already delaying the achievement of the MDG 1 (eradication of extreme poverty and hunger) and the anticipated climate change will further add to uncertainties. Development of adaptation and mitigation strategies needed to cap this, require new knowledge combined with indigenous knowledge. New agro-management techniques, including conservation agriculture, coupled with enhanced genetic makeup of crops and livestock to tolerate emerging biotic and abiotic stresses, will help to optimize the production under ever growing climate change. Better understanding of the implications of the increase in temperature, not only on the global and regional scale, but also at the level of different local agro-ecological zones, will help to cope with shifts in the suitability of different crops and cropping sequences. The use of advanced simulation models to deal with coping mechanisms related to the impact of climate change and developing computer expert systems for adaptation to these changes will help extension personnel to work with the communities in order to accommodate new types of agriculture. This effort cannot be done by one single country; it requires networks of scientists and experts around the world to build up this knowledge in a form which can be used by the developing countries, and calls for massive human resource development programs. A fundamental shift in Agricultural Knowledge Science and Technology (AKST) capacity development is required, along with policies and institutions, with much increase in investment, as responding actions to the new changing circumstances. Success would require increased public and private investment in AKST and the development of supporting policies and institutions. Small-scale farmers would benefit from greater access to knowledge, technology, and credit, and critically, from more political power and better infrastructure. Scientists must work more closely with local communities, and traditional practices must have a higher profile in science education. Food security strategies require a combination of AKST approaches, including the development of food stock management, effective market intelligence and early warning, monitoring, and distribution systems.

Introduction

The issue of climate change, as it may affect the sustainable development of dry areas, had been the focus of the 9th and 10th International Dryland Development Conferences held in 2008 and 2010, respectively. The deliberations in those conferences highlighted the need for moving from

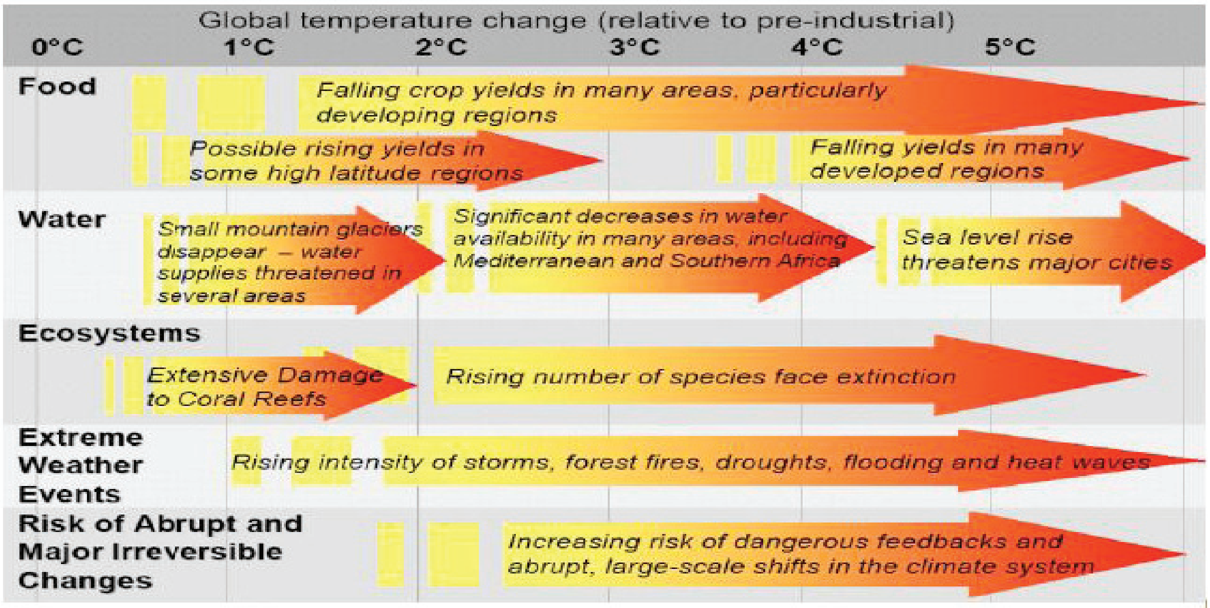
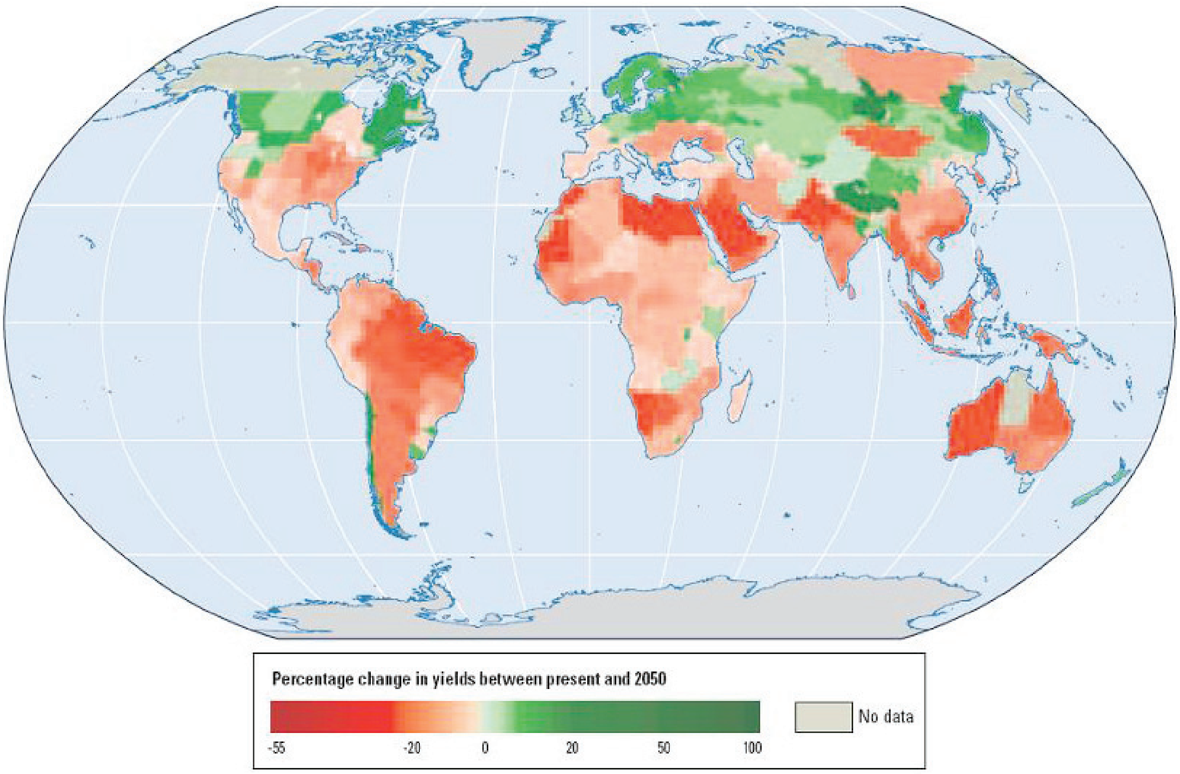


Figure 1: Major impacts of global temperature changes relative to pre-industrial period.



Sources: Müller and others 2009; World Bank 2008c.

Note: The figure shows the projected percentage change in yields of 11 major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soybean, groundnut, sunflower, and rapeseed) from 2046 to 2055, compared with 1996–2005. The values are the mean of three emission scenarios across five global climate models, assuming no CO_2 fertilization (a possible boost—of uncertain magnitude—to plant growth and water-use efficiency from higher ambient CO_2 concentrations). Large negative yield impacts are projected in many areas that are highly dependent on agriculture.

Figure 2: Percentage global yield losses (present to 2050) because of the projected climate change.

global to regional and local-level assessment of impacts of climate change on agriculture and livelihoods of dryland communities so that appropriate strategies may be developed that may enhance their resilience to the adverse impacts of climate change. This 11th Conference is taking the subject of climate change further in the context of food and energy security in the dryland areas.

There is now compelling evidence that climate change is really happening and is a serious sustainable development challenge and not just an environmental issue. It is also recognized that climate change impacts will affect all countries but the developing countries and the poor will bear disproportionately high negative impacts. Consequently, climate change will undermine the ability of the developing countries to achieve the Millennium Development Goals. An study by the World Resources Institute has shown that the potential of agriculture output in the year 2080, as compared to the year 2000, would be negatively affected by climate change globally (about 3.5 % reduction), but it will be nearly twice as much in the developing world (nearly 7% reduction). In contrast, in the industrialized countries there might be an increase in the potential of agriculture output by nearly 7%. The loss of potential output is predicted to be the greatest in Africa, followed by Latin America, Middle East and North Africa, and Asia.

The changing environment is posing a great challenge for food and energy security in the dry areas, which are characterized by poor and fragile natural-resource base and rampant poverty. Globally over 2,000 million hectares of land is already degraded in the dry areas, where there is loss of biodiversity, increase in water scarcity, increase in population pressure, and destruction of natural resources because of civil conflicts and war. The impact of various scenarios of rise in temperature (IPCC 2001), relative to preindustrial period, on food, water, ecosystems, extreme weather events, and risk of abrupt and major irreversible changes is shown in Figure 1.There is already an early indication that this trend will continue (early drafts of IPCC ARS5).

Impact of temperature rise on crop yield and quality

The projected percentage change in yield of 11 major crops, including wheat, rice and maize, in the period 2046 -2055 in comparison to the period 1996-2005, averaged over three emission scenarios across five different global climate models, is shown in Figure 2. Apparently, large negative impacts are projected on these crops in many dry area countries that are highly dependent on agriculture.

In many dry areas the reduction could be over 50%, which could have severe consequence for food security. Some of these reductions could be attributed to increased incidence of diseases on the staple food crops. For example wheat has been found to become more susceptible to rust diseases at higher temperatures. Even for crops like tomatoes, which should do better with warmer summers and longer growing season, higher temperatures at critical reproductive stage can cause conspicuous yield reductions. A few moderate heat stress days can have a negative effect on quality, reducing marketable yield, even if total yield of tomatoes stays the same or goes up. Similarly, apple yields are below average in those years with warmer winters perhaps due to the premature blooming followed by cool temperatures that harm apple blossoms and/or fruit set.

We must also expect that insect pests, weeds, and disease pathogens will be responding to climate change in different ways, as well as beneficial organisms both above- and below-ground.

Successful crop production often relies on precise synchrony between organisms, such as the presence and activity of pollinators when flowers are at peak pollen shed, the presence and activity of natural enemies of insect pests to keep them at low population levels, etc. Some of this synchrony could be disrupted by climate change because species will differ in their sensitivity and response to climate change. Warmer conditions can increase the problems of pest infestation. For example aphids, which are a serious pest of a range of crops, grow exponentially as the temperatures increase. Climate change will also exacerbate problems with new invasive weed, insects and diseases.

Effect of sea level rise associated with global warming

Another serious impact of global warming on agriculture food production would occur through the rise of sea level. Because of global warming over the period of time, the rise in sea level as predicted by different models is shown in Figure 3 (IPCC 2001). Range is from a few cm to nearly a meter depending on the model adopted and the time frame. This could lead to submergence of productive lands and urban and industrial settlements in the coastal areas.

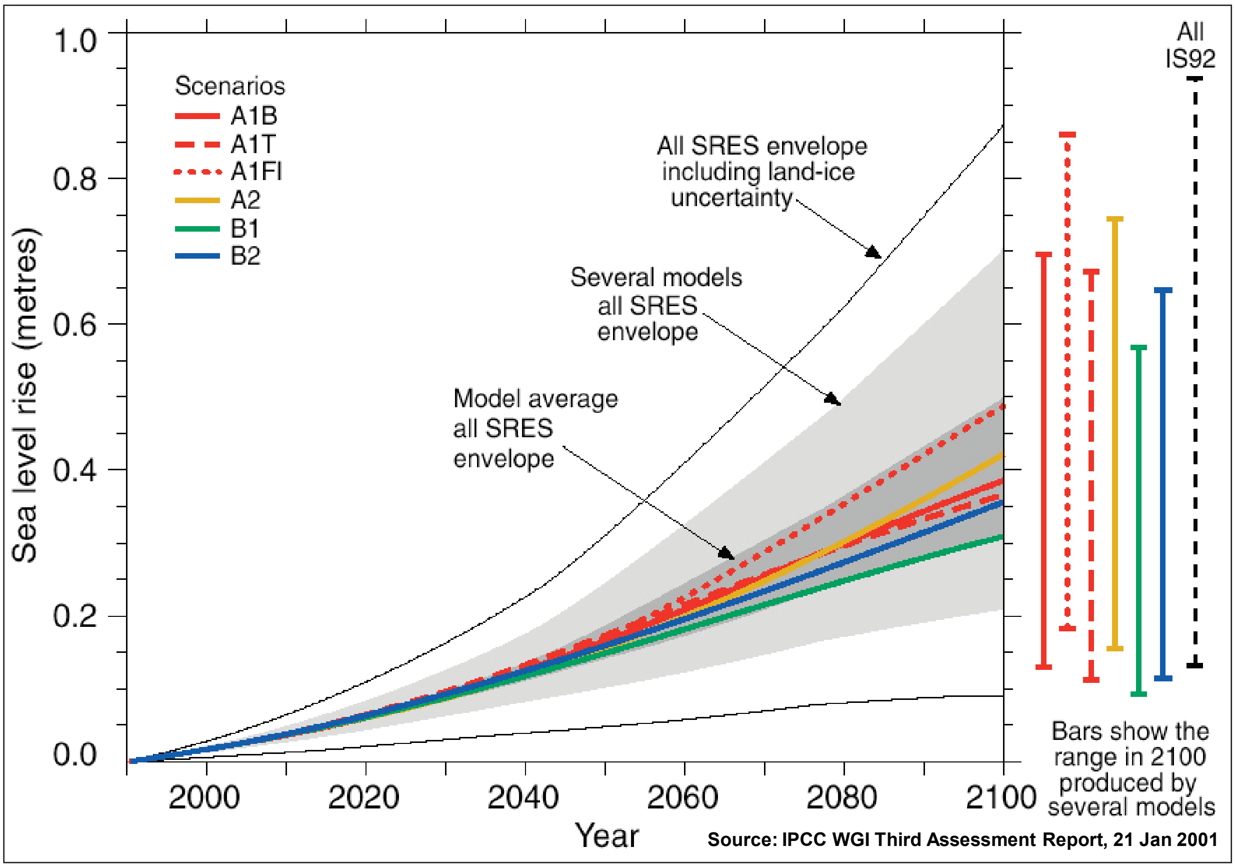


Figure 3: Sea water rise predicted by several models used by IPCC for future climate changes.

According to UNEP/GRID-Arendal report (Simonett 2005), the following two scenarios of displacement of people living in the Nile Delta were suggested. If the sea level was to rise by about 50 cm, some 1800 Km^2 crop land in the Nile Delta alone could get submerged affecting the livelihoods of some 3.8 million people living there. If the rise were one meter, as some models predict, some 4500 Km^2 crop land would get submerged there affecting some 6.1 million people (Fig. 4).

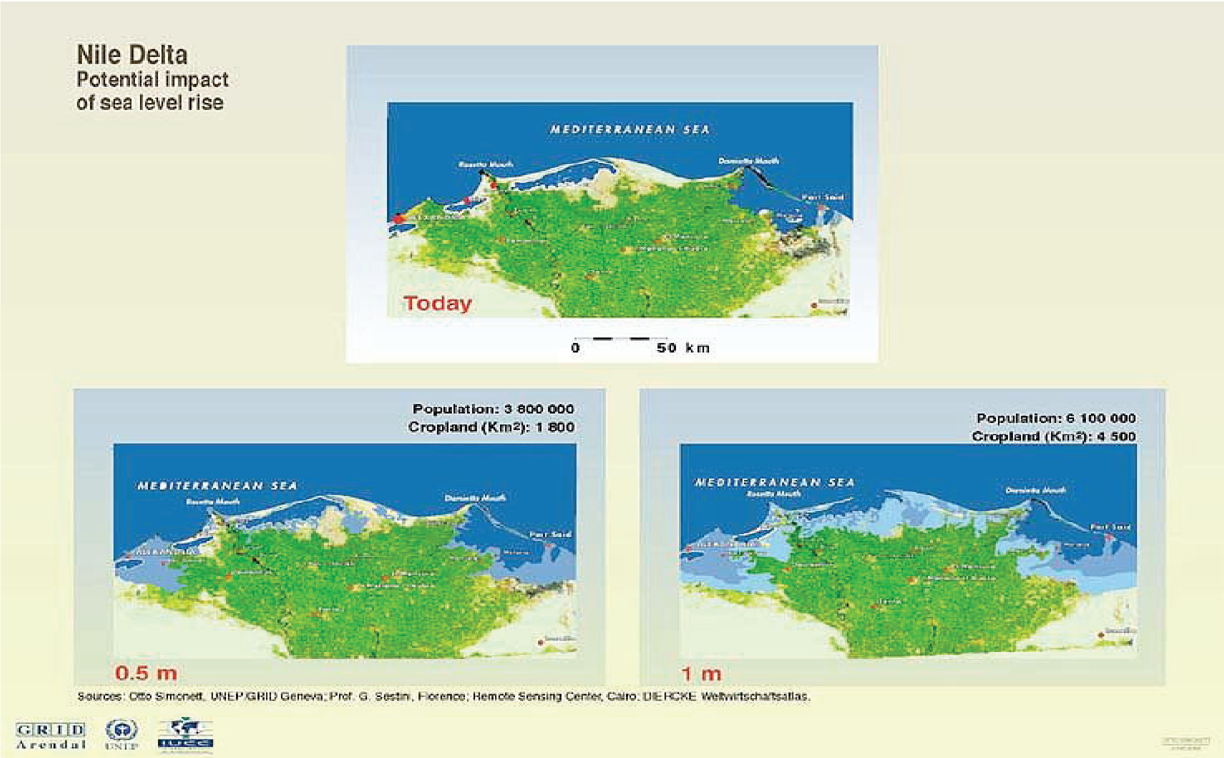


Figure 4: Potential impact of sea water rise in Nile Delta.

This would put enormous pressure on the food security of Egypt that is already under stress because of rising population and decreasing water supply for agriculture. In 1928, a German architect, Herman Soergel, suggested to construct a hydroelectric dam across the Strait of Gibraltar, the so-called Atlantropa Project, which could lead not only to power generation but also lower the level of the Mediterranean Sea (Sörgel 1932; Cathcart 1985), thus opening some possibility of physical adaptation to cope with this problem (Fig. 5).

Precipitation changes in the dry areas and impact on food and social security

According to SRES A2 model, the dry areas of Middle East and North Africa (MENA) region would witness a reduction in rainfall in the coming 50 to 100 years. This would further aggravate the problem of food insecurity in the region, could enhance poverty, and force the people to migrate out. South to North migration around the Mediterranean Sea is already occurring and is posing a serious threat to social security in the Mediterranean Basin. According to a study conducted by the European Commission (EC 2010) on labour market performance and migration flows in the Mediterranean Arab Countries (MACs) some 4.7million official migrants from MACs lived in EU 27 in 2006 and another 6.3million in rest of the world. This trend will continue because of the

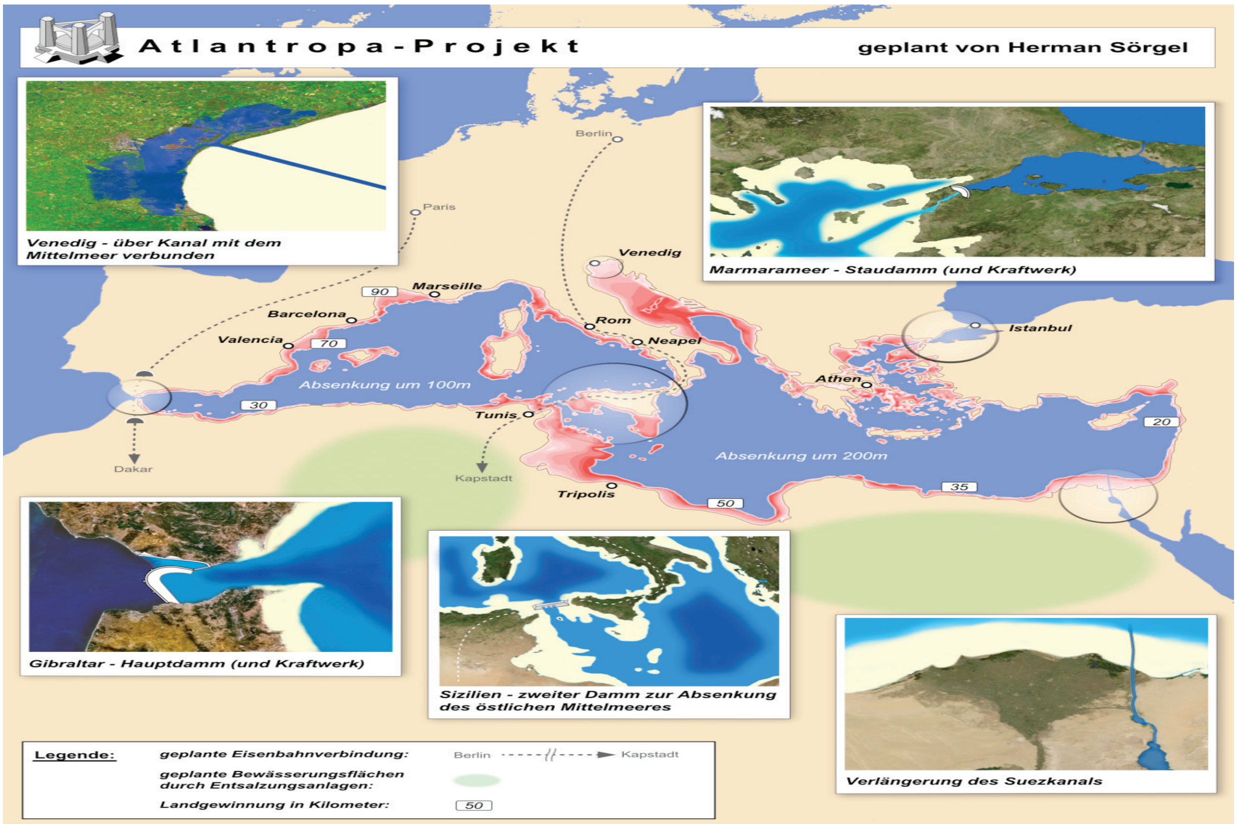


Figure 5: Atlantropa Project as proposed by Herman Soergel.

adverse impact of climate change on the employment and livelihood of the people in the MENA region in the future and increase the migration pressure in the Mediterranean Basin. Unless new jobs are created or alternative employment opportunities are provided, there will be increasing unrest in the MENA region as this migration is mainly a result of lack of job opportunities and gainful employment in agriculture sector in the rural areas. A modern and advanced sustainable agricultural development with emphasize an agro-industry could provide employment in rural areas.

Food and energy security linkages and climate change impact

Agricultural production is sensitive to changes in energy prices, irrespective of whether the changes are caused by world oil markets, national policies to achieve environmental goals, or policies to enhance energy security. Increased energy price will impact the cost of production because the price of each agricultural input and production process (herbicide, pesticide, fertilizers, fuel for farm operations and transport of produce) is intimately linked to energy price. This would thus lead to reduction in the planted area and production and increase in crop prices in the developing countries (Fig. 6 and Fig. 7).

An FAO study shows that there has been a steady increase in food price index from 2000 to 2011. It is linked to increase in the price of energy, but some of this increase is also attributed to the use of food crops to produce biofuels, for which the developed countries are giving subsidies to meet their environmental goals. The increase in food price is a matter of grave concern to the developing countries, particularly those with large dry areas, as their food security is dependent on food imports.

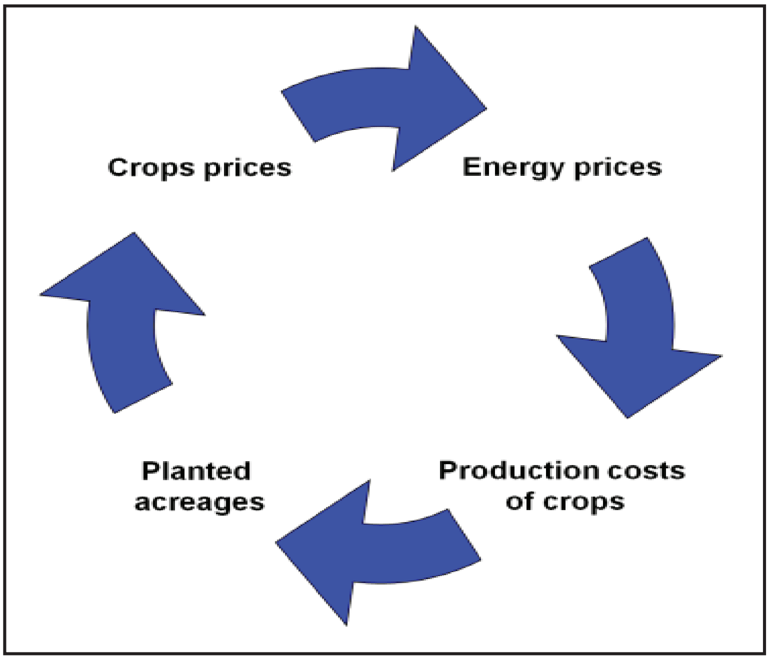


Figure 6: Inter-linkage of energy prices to prices of crops.

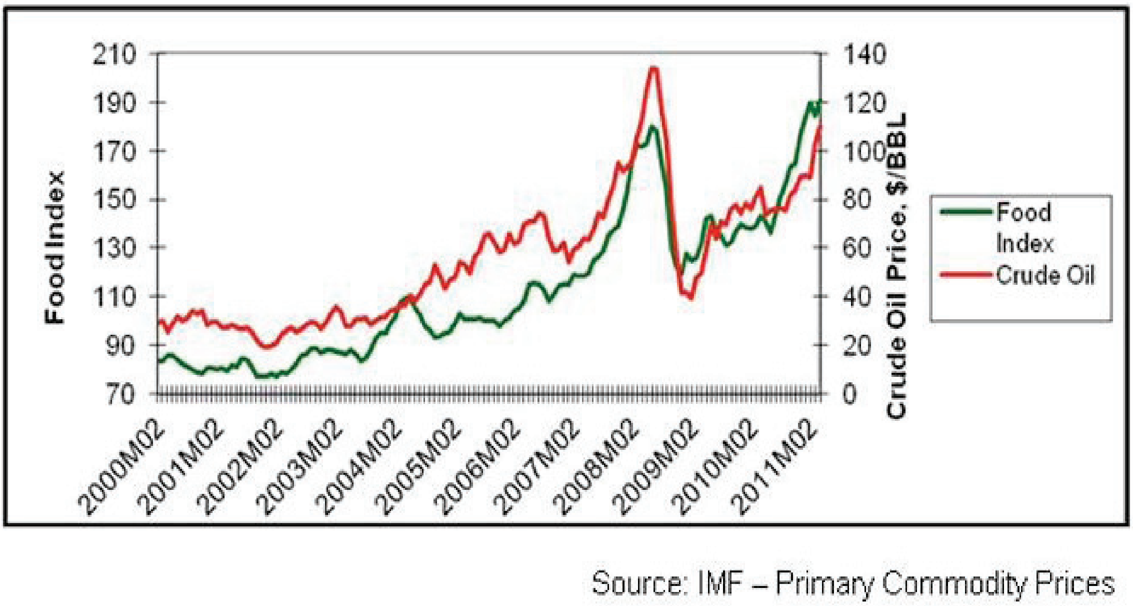


Figure 7: Food price as related to oil price.

Climate change, with its adverse impact on productivity, is predicted to further lead to increase in prices of various food crops and products (Fig. 8; Willenbockel 2011) .This would make it more difficult to the developing countries to meet the MDG by 2015.The reasons for hunger are a nexus of poor harvest and low yields, high food prices, and low income of the people and unemployment. Climate change in the dry areas would directly or indirectly impact all these components leading to accentuated hunger and malnutrition amongst the poor communities.

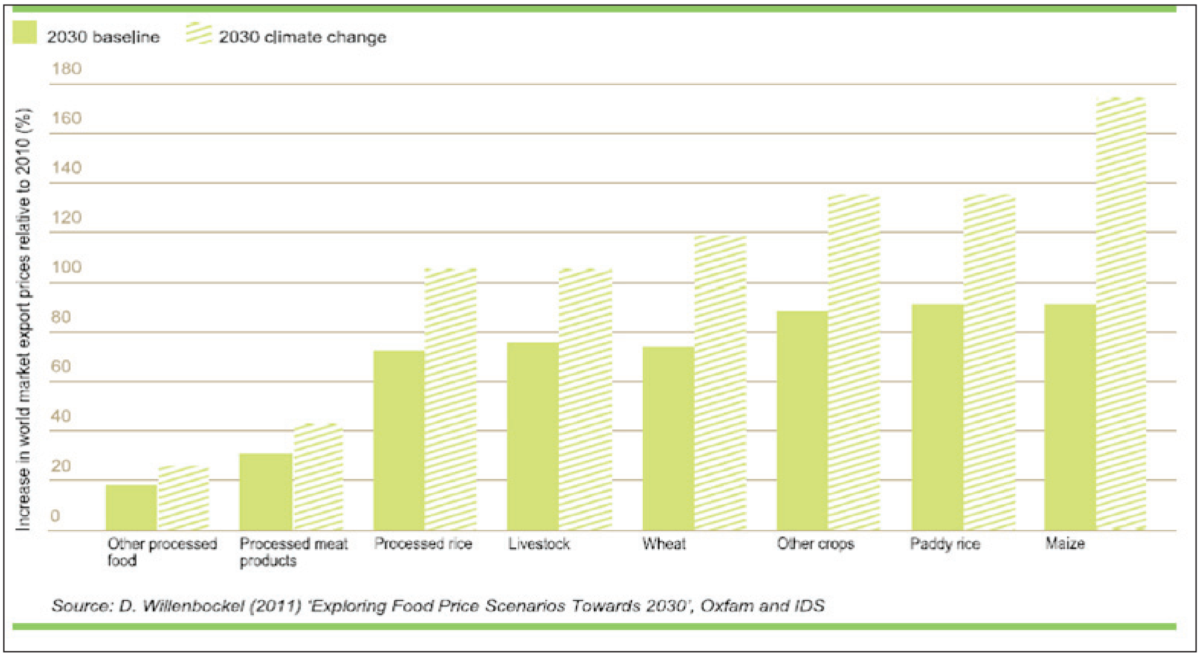


Figure 8: Real food price changes by 2030 over 2010 base line as affected by predicted climate change**.**

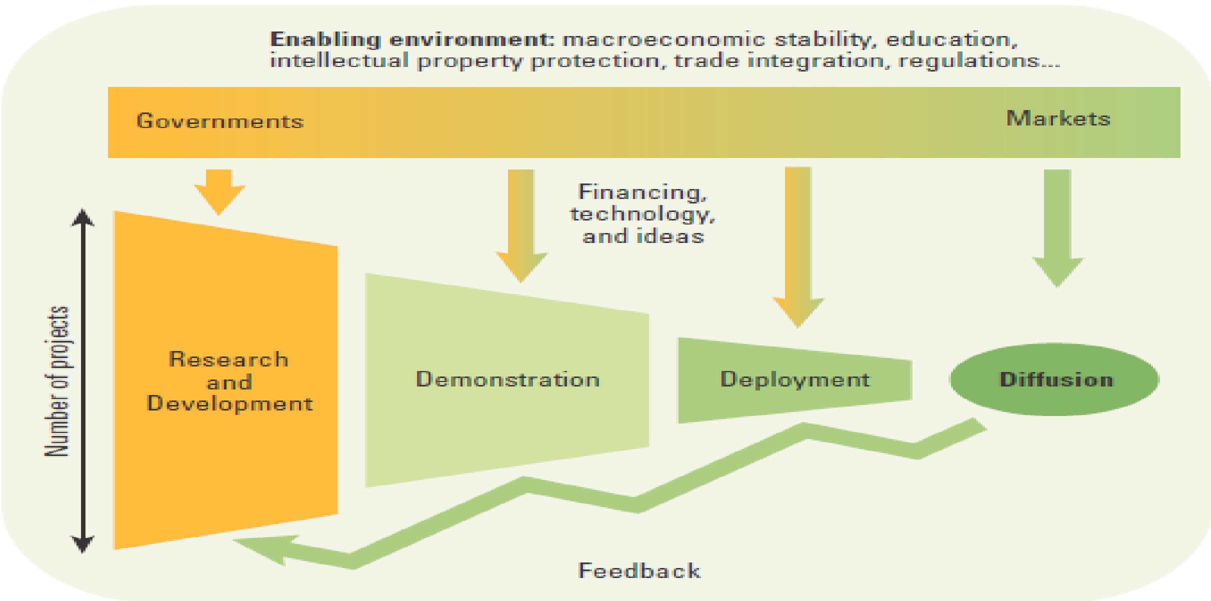
Rescue package for achieving the MDG 1

The key challenges that confront agriculture in the developing countries include: (a) insufficient aid to agriculture; (b) failure to meet aid effectiveness commitments as the agricultural aid programmes are particularly poorly coordinated among donors; (c) insufficient spending on agriculture by developing countries; and (d) failure to spend on supporting sustainable smallholder agriculture and other services targeting the poorest. Agriculture expenditure halved in Asia and sub-Saharan Africa and declined by two-thirds in Latin America. In India, where the largest number of hungry people reside (over 200 million), agriculture receives just 3.7% of government spending. FAO notes that the countries with the least hunger tend to have higher expenditures on agriculture whereas the countries enduring most undernourishment tend to spend less. There will be a need for a massive increase in global spending on food security by at least $40 billion per year. The countries of the developing world will have to develop a national MDG 1 'rescue plan' with donor support as part of a time-bound well resourced strategy and shift agricultural spending towards the services which support smallholder agriculture and the rural poor.

Role of science and technology and regional and international cooperation

New tools of science and technology have the potential to bring about needed changes when properly incorporated in the R&D efforts of the developing countries. The technologies include remote sensing, GIS/GPS; biotechnology/genetic engineering; genomics and proteomics; simulation modeling; information technology/ expert system/ advanced artificial intelligence; harnessing renewable energy (solar, wind, biofuel); new energy-saving techniques for desalination and water transportation; and nanotechnology (biosensors, bioprocessing, nano-materials). Harnessing these technologies for the benefit of the poor in the dry areas will necessitate cooperation at regional and international levels for human resource development and assured development aid. Overseas Development Aid for agriculture, so vital for R&D needed to cope with the emerging challenges of food insecurity arising from population increase in the developing world and impacts of climate change, is relatively low as the Clean Energy Progress Report (OECD/IEA 2011) has indicated: The ODA for agriculture worldwide was only $9.8 billion in contrast to industrialized countries' support to their own agriculture of $252 billion (of which the subsidy for biofuel production alone amounted to $20 billion), while the worldwide subsidies for fossil fuel consumption was $ 312 billion.

At the same time, the governments of the developing countries themselves have also got to allocate larger proportion of their GDP for development of agriculture and to boost the R&D efforts targeted to small and marginal farmers, who, with needed empowerment and support, could become key players in enhancing the food security. Development of rural infrastructure could enable these farmers to get full benefit from their agricultural vocations. There are examples emerging in the recent years that show this potential of policy reforms and infrastructure support (Fig. 9). For example in Tanzania, the Agricultural Sector Development Strategy (ASDS) and the recent Kilimo Kwanza (Agriculture First) initiatives built rural roads, irrigation and grain storage facilities. The Road Fund itself led to a 27% increase in good roads, which helped link farmers to food markets. The food poverty in Tanzania has fallen by 11% between 2001 and 2007.



Source: Adapted from IEA 2008a.

Figure 9: Policy reforms are vital for innovation chain needed to achieve sustainable agricultural development.

Innovative financing schemes are proven to enhance the ability of farmers to access input markets. For example in Nigeria, National Special Programme for Food Security resulted in a near doubling in agricultural production and farmers' income. Farmers were able to buy inputs using interest-free loans to be repaid following harvest. In Bangladesh, $107 million was being distributed in the form of Agriculture Input Assistance Cards, targeting poor households. Of the total 18.2 million farmers in Bangladesh, 9.1 million marginal, small and medium farmers are eligible for the cash subsidy.

Science and technological intervention options can be identified that not only would ensure food security and sustainable use of natural resources but could also contribute to mitigation of climate change (FAO 2009; Fig. 10). Sustainable farm resource management and crop husbandry, based on restoration of degraded lands, expansion of low energy-intensive irrigation, improved fallow management through introducing cover/catch crops and judicious residue management, conservation tillage, diversification of cropping including introduction of agroforestry, and improved soil nutrient management, have high potential of ensuring not only food security but also contribute to climate change mitigation through increased carbon sequestration. In contrast, expanding the energy intensive commercial agriculture and bringing marginal lands under cropping might help in food security but would have high environmental cost.

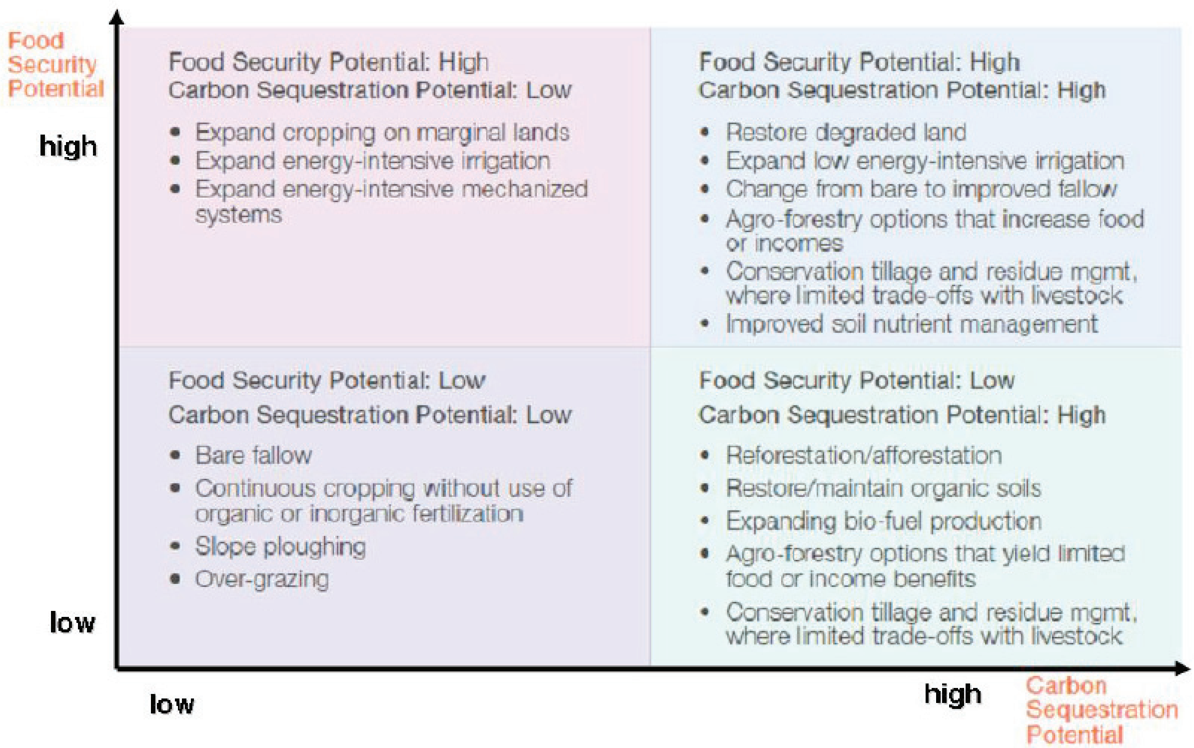


Figure 10: Agriculture Knowledge Science and Technology (AKST) options and their potential impact on food security and climate mitigation (source: FAO 2009).

Achieving food security in the face of climate change would necessitate good knowledge of the local and regional impacts of these changes as the global assessment would not permit developing cost effective local interventions for enhancing resilience of the farmers, permit adaptation and also contribute, in the end, to mitigation of climate change.

Drought and high temperature stress are two major contributors to reduction of yields of staple crops due to the climate change in the dry areas. Hence, adaptation to these stresses would be an important strategy, where the role of new biotechnologies will be crucial. For example, the Egyptian Scientists have already developed drought-tolerant genetically-modified wheat. Heat tolerant wheat have been developed and released in several parts of Central Asia, West Asia and South Asia region through breeding efforts of the national scientists in collaboration with their international colleagues from the CGIAR system. Scientific efforts have made it possible to combine high yield potential with drought tolerance in bread wheat, which is important for stabilizing yields under variable moisture supply conditions. Drought tolerant maize genotypes have been developed for drought prone areas of developed and developing world through an effective scientific partnership between the public and private sectors, and farmers are benefitting from them.

The average annual per capita renewable supplies of water in the southern Mediterranean countries is now less than 1000 m^3, well below the world average of about 7000 m^3, and that of the northern Mediterranean countries of 5000 m^3 (Fig. 11). The average is close to the threshold for water poverty level (1000 m^3) and some countries in the region are already below absolute or severe poverty level of 500 m^3, such as Jordan. Only 8 of the 23 WANA countries have per capita water availability above the water poverty level. Mining groundwater is now a common practice in the region risking both water reserves and quality. In many countries securing basic human water needs for domestic use is becoming an issue not to mention the needs for agriculture, industry and environment. Agriculture continuing to be the major user of water in the form of irrigation, the increasing shortage of water in the dry areas of the Middle East and North Africa will necessitate improving the water use efficiency. Micro-irrigation and other efficient management systems for increasing irrigation efficiency, including laser leveling, broad-bed planting, and alternate furrow irrigation, will have to be promoted. Use of hydroponics and other soil-less protected agriculture systems that reduce water use and permit recycling of water will be important.

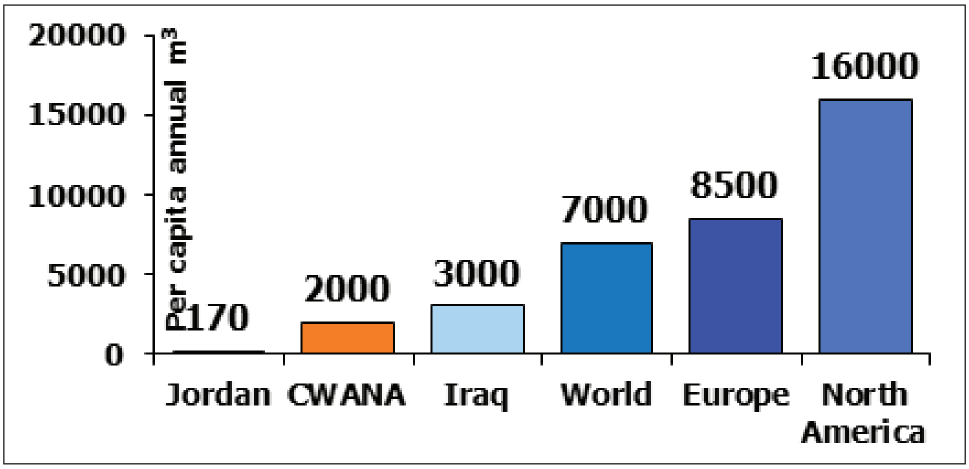
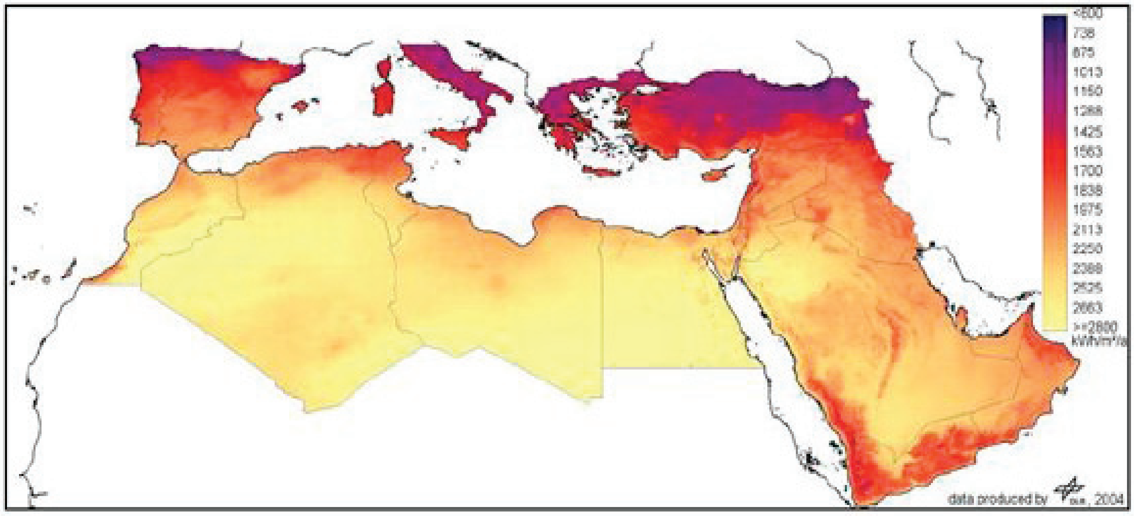


Figure 11: Annual renewable water supply per capita in different regions.

Science and technology advances will permit better utilization of such renewable energy sources (solar radiation, wind power, geothermal energy) thus reducing the need to divert food crops for biofuel production. The region of WANA has particularly high annual direct normal solar irradiance (Fig. 12) giving opportunities for harnessing it for renewable energy. However, this will necessitate major scientific and technological innovations for developing cost-effective techniques for harvesting and storing solar energy. China, Germany and France are already taking a lead in this area. Again, harnessing solar power would call for greater North-South and South-South collaboration. The industrialized countries could make greater commitment to this as a mitigation strategy for climate change.



(Source: German Aerospace Center, Institute of Technical Thermodynamics)

Figure 12: Annual direct normal solar irradiance in West Asia and North Africa region and Southern Europe.

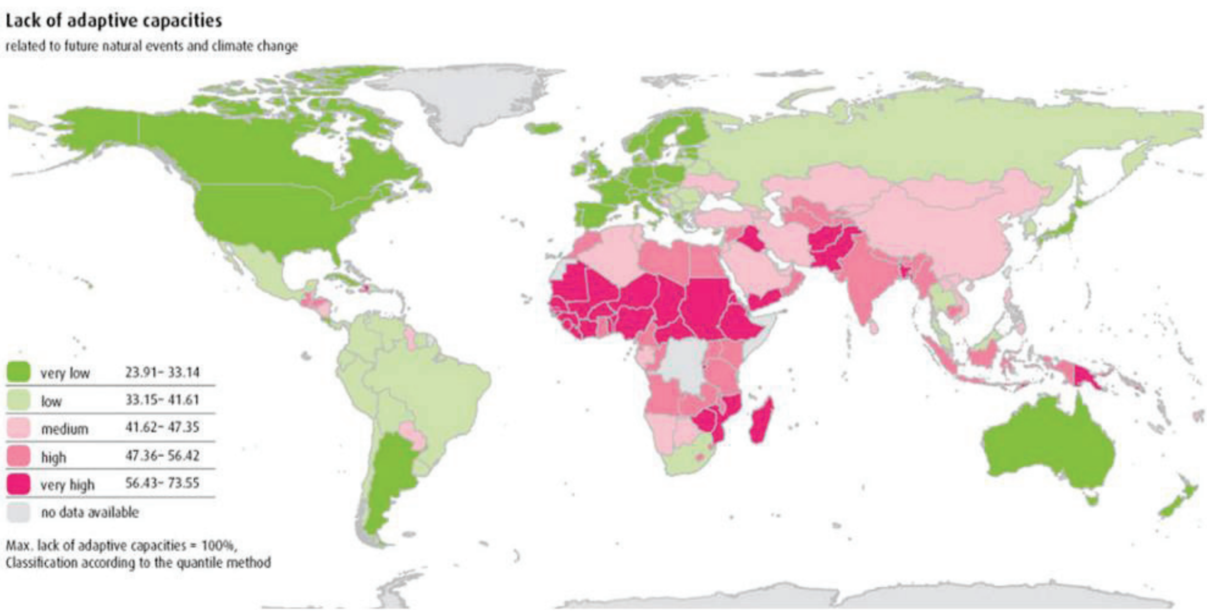


Figure 13: Lack of adaptive capacities related to future natural events and climate change in different parts of the world.

Fortunately, the recent Cancun Agreement provides for 'Green Climate Fund' and 'Technology Mechanism', which could prove as game changer if the commitments are honestly put to action. The Green Climate Fund is to support projects, programmes, policies and other activities in developing country, using thematic funding windows. The Technology Mechanism is to facilitate enhanced action on technology development and transfer to support action on mitigation of and adaptation to climate. The Mechanism consists of two key components: a Technology Executive Committee and a Climate Technology Centre and Network.

Figure 14: Enhancing coping and adaptive capabilities through optimization and enhancing synergies between international, regional and nation systems

International cooperation and collaboration in leveraging the power of science and technology is the mantra to ensure global food and energy security and eliminate poverty in the face of climate change. Nowhere will this realization be truer than in the dry rainfed areas of the developing world. It is evident from Figure 13 that there is a lack of adaptive capacity of the countries in the dry areas (Harmeling 2008). Therefore, there is a need for enhancing the coping and adaptive capacity through optimization and enhancing synergies between international, regional and nation systems within the context of global research system of AKST (Fig. 14).

Since its inception 34 years ago, the International Dryland Development Commission has committed itself to promote this collaboration to improve the livelihood of 2.5 billion people living in the dry areas and thus contribute to world peace and prosperity.

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Water, food and energy security in drylands: Challenges triggered by global changes

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Abstract

The global drylands – comprising over 40% of the land surface area – are facing a triple threat as a result of a number of converging global crises: increasing water scarcity, decreasing food supply, and inadequate access to modern energy services. The global crises that are fueling these threats are multiple, but interlinked, including global climate change, booming population (particularly in drylands countries where this is also coupled with changing demographics and rising 'youth bulge'), political upheaval (including the so-called 'Arab Spring'), sharply rising food prices, and increasing unemployment amongst the youth. As a result of these threats, governments, civil society, the international development community and the United Nations system are all concerned about the nexus of water, food and energy security – these form a triangular relationship that ultimately has a bearing on national security, societal stability and environmental sustainability. Pulling on any of the apexes of the triangle has direct and profound impacts on the other two. Water is critical to food production and energy generation at all levels. Food production, processing and transport require energy resources while water utilization is embedded within each step. Sufficient and modern energy supply – both renewable and non-renewable – requires water, but is also increasing overlapping with food production as many dryland countries are eyeing biofuel production in lieu of growing food crops. Since 2008, food prices have been rising sharply – FAO predicts that the era of "cheap" food is over; this volatility in the international food market can also be directly correlated to malnutrition, poverty and political unrest. While we may presently have sufficient food, water and energy at the global aggregate level, drylands region are very strongly disadvantaged in terms of this triple security nexus. The situation may be further exacerbated in the coming decade or so as increasing affluence may put incremental demands on water, food and energy. We no longer have the luxury to plan and design policies and approaches for addressing water, food and energy security independently of each other – getting this right is much more critical for drylands. Despite this obvious strategic interest, spanning traditional sectoral divides is not easy; policy inertia would perhaps be the greatest hurdle. This paper discusses emerging ideas for policy integration, including some case studies from dryland countries. These ideas link directly with a new international economic and social development regime that is emerging as we approach the conclusion of the Millennium Development Goals in 2015, and look beyond.

Drylands' issues and challenges – The context

The Millennium Ecosystem Assessment completed a comprehensive assessment of the global drylands and desertification trends (MA 2005). It was pointed out in the MA report that the land degradation and desertification trends will continue unabated in the coming decades. The situation seems to be further escalating due to convergence of social factors like rapidly changing population demographics, increasing levels of unemployment, political upheaval and sharply rising food prices. Let's analyze each of these social factors in some detail.

A significant challenge for the drylands region is the so-called 'youth bulge' – portion of population between the ages of 15 and 24. Recent trends in drylands regions have approached alarming proportions (Orenstein *et al.* 2011). For example, the Arab region (which is predominantly characterized as drylands) has 121 million children and 71 million young people (Mirkin 2010). The United Nations Development Programme (UNDP) projects that these numbers will climb to 217 million by the year 2050. Similar trends in growing youth bulges are available for South Asia, East Asia and Sub-Saharan Africa. These are often linked to increasing urbanization and high levels of unemployment (Urdal and Hoelscher 2009). The unemployment is driven by relatively poor economic conditions. As shown in Figure 1, the drylands countries in Asia, North Africa and Sub-Saharan Africa fall significantly behind the global average in terms of their Gross Domestic Product (GDP) per capita. We must also recognize the role agricultural activity plays in dryland regions, particularly in Sub-Saharan Africa where it accounts for more than a quarter of the GDP.

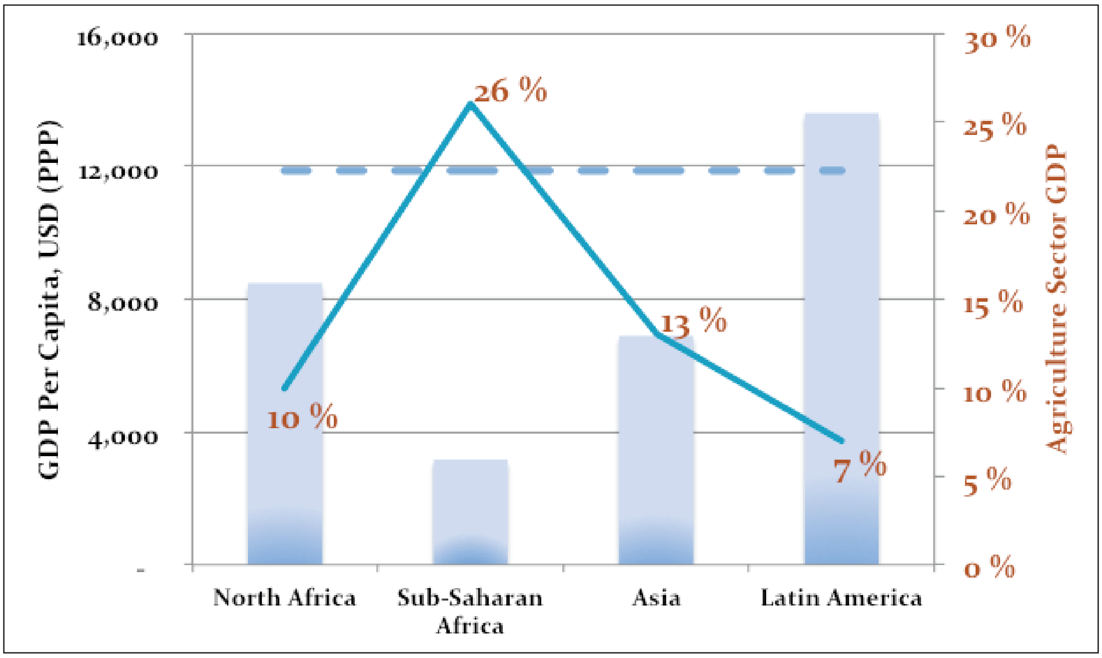

Figure 1: Economic trends in drylands countries, by region (data source: CIA 2012).

Many have argued that the increasing political upheaval, most notably the Arab Spring (e.g., in Algeria, Bahrain, Egypt, Libya, Oman, Qatar, Syria, Tunisia and Yemen), can be linked to the youth bulge and rising unemployment. Urdal (2006) argues that large youth cohorts are statistically associated with increase in social unrest and conflicts at the national level; well-managed cities could help reduce this risk.

Another important and related trend is the hike in food prices in the international market. There has been a sharp rise and extreme volatility in food prices since 2008, as shown in Figure 2 for cereals; this directly contributes to the corresponding rise in trends of malnutrition, poverty and political volatility; this trend impacts drylands countries in the worst way. It can be projected that climate change, higher energy prices and the global water crisis will make food harder and more expensive to produce. Organization for Economic Cooperation & Development (OECD) and United Nations Food and Agricultural Organization (FAO) predict that the era of cheap food prices is over, and higher prices for agricultural products are projected for the next ten years when compared to the pre-2007 decade (OECD/FAO 2013). To state the obvious, small-scale farmers and consumers living below the poverty line would be the hardest hit in drylands developing countries.

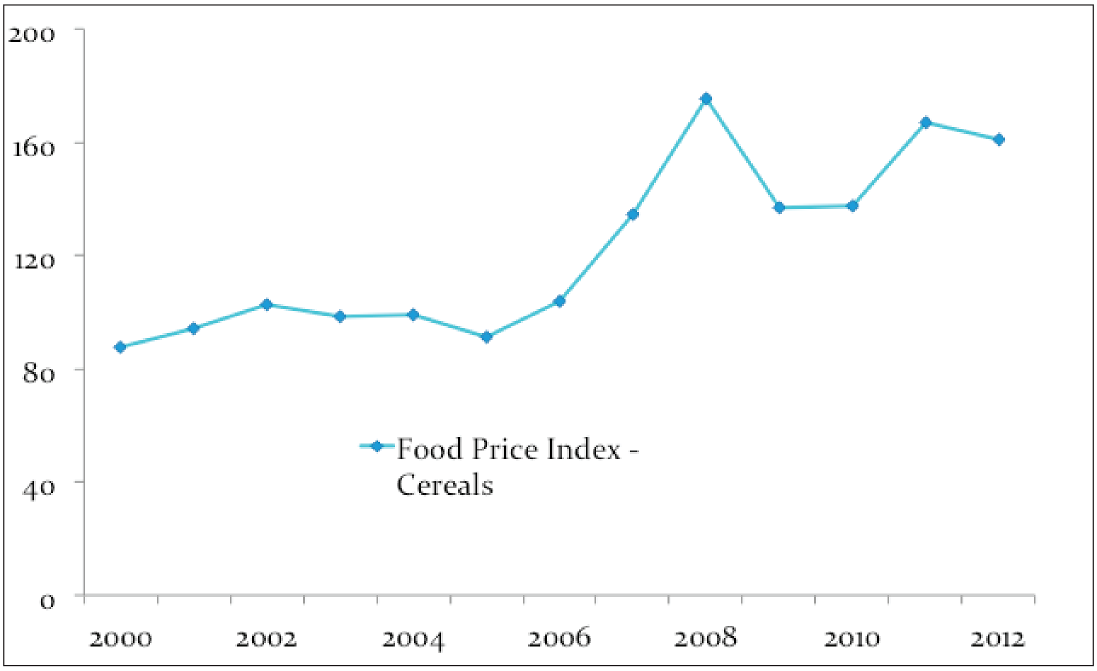

Figure 2: Trends in Food Price Index for cereals over the past decade (data source: FAO Aquastat).

Recent analyses demonstrate the water scarcity and drought are likely to be the determining factor in ensuring food security. These linkages will be important as about 60% of the global population is projected to suffer from water scarcity by the year 2025 (UNEP 2007). It can be argued that water scarcity is the single greatest constraint in securing the food supply of hundreds of millions of people worldwide; this is further discussed in the next section.

The water-food equation

Agricultural production consumes the largest fraction of available freshwater; this fraction is about 70% at the global scale (WWAP 2012). However this fraction is much higher in dryland countries, ranging from 80% to 95%, indicating a much greater dependence on irrigation for achieving food security. Trends projected by the Intergovernmental Panel for Climate Change (IPCC) indicate that most of the drylands countries will have a reduction in precipitation of up to 20% by the year 2050, further exacerbating the food security. Cumulatively, the demand for food-on-the-plate is set to rise by 70% by the year 2050 (WWAP 2012).

The good news is that all of the increase in food demand does not need to come from increase in production alone; increased efficiency in food value chain, reduction of food wastage from field to fork, and production of more crop per drop of water would help ease off the related water stress to some extent – which is predicted to rise by about 20% by the year 2050. In order to fully avail these opportunities for increasing efficiency and productivity while minimizing wastage would require: high prioritization at the governmental level, investments in efficiency and productivity approaches, enabling policies that drive changes to production and consumption patterns and empowering small-holder farmers to better compete in the international food market.

The water-energy equation

The nexus between water and energy is another important dimension for drylands that has implications for social and economic development. The US Energy Information Administration predicts that there will be a 50% increase in global energy demand by the year 2035 (EIA 2010). Most of this growth in energy demand will come from developing countries as their populations and economies grow at a considerable rate (WWAP 2012). As energy production is increased, it will have a direct impact on water consumption patterns worldwide – most notably by the energy sector itself. While all forms of energy generation, including oil, coal, natural gas, nuclear as well as renewable resources, exercise a water footprint, two forms particularly stand out: hydropower generation and biofuel production.

In case of hydropower generation, there is a concomitant benefit in better water resources management and improvement in irrigation water supply; there are also significant environmental impacts and some social impacts that must be analyzed through a dispassionate analysis. The most compelling case is that for the Sub-Saharan Africa. As shown in Figure 3, most of the drylands developing countries in Sub-Saharan Africa have large fractions of their populations living without access to a power grid. Overall, one in four people in Africa have access to electricity through a power grid, about 360 million people are without access to the power grid or another modern form of energy. In this equation hydropower supplies 32% of Africa's energy demands. Conversely, the World Bank estimates that only 5% of hydropower potential is exploited in Africa (WWAP 2012).

The most common biofuel production option in Africa is bio-diesel, which is made from oil rich seeds including soya, oil palm, jatropha and algae. Other biofuels, like bio-ethanol, are also in use – the broad variety of technologies and production process makes it difficult to arrive at generic figures about water consumption. It is anticipated that in order to produce some 20 million tonnes of oil equivalents by the year 2050, an additional 20% of agricultural area would need to be dedicated for biofuel crops (WWAP 2012). When combined with increased food demand, this can lead to a drastic impact on water consumption patterns. There is a further degradation of water quality, through use of fertilizers and chemicals for biofuel crop production. Most importantly, diversion of agricultural land and irrigation water to biofuel crop production would mean that biofuels would *de facto* become a strong lever for the international food prices.

Overall it is important to keep in mind that water, food and energy constitute a triangular relationship. Pulling on any one of the apexes of this triangle would lead to changes in the other two. The luxury of defining water, food and energy policies independently of each other is no longer there. However, there are very few pragmatic examples how this can be achieved. In particular, government ministries dealing with the three sectors often operate in isolation and are driven by dedicated budgets. Recent research work on water security has shown that it may be the glue that can bring together the three areas; this notion is further described in the following section.

Water security in the international context

The notion of water security has received political and policy attention in the last few years. A number of high-level events at the periphery of the UN General Assembly indicate that this topic

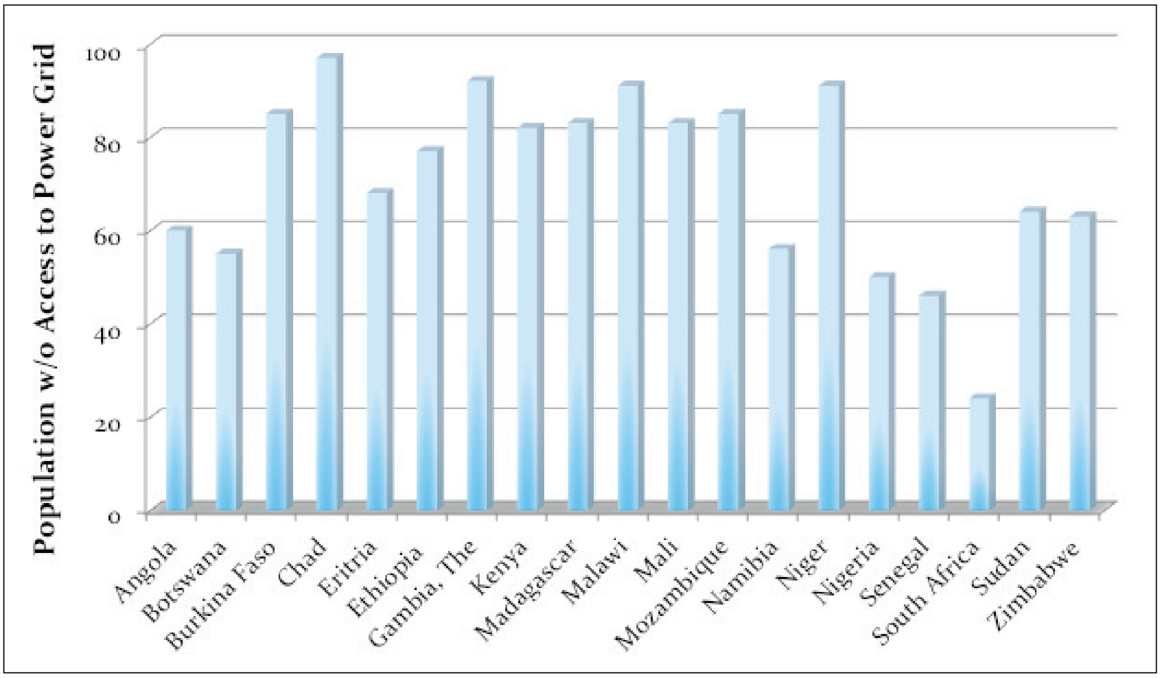

Figure 3: Access to electrical power grid in drylands countries of Sub-Saharan Africa (IEA 2012).

is relevant in the international community and is linked to the ongoing debate on the post-2015 development agenda (Bigas 2012). Most recently, UN-Water has defined water security as: "*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*" (UN-Water 2013). This definition embraces a broad range of issues and signifies that water is central to achieving security, sustainable economic growth and development, and meeting the basic needs of safeguarding human health and wellbeing (please see Box 1 for details of the water security).

In order to achieve water security, cooperation is essential across borders and across sectors, and involving all stakeholders, as water security is a multi-dimensional and crosscutting issue that cannot be solved on its own. Cooperation in order to achieve water security will require adequate institutions and sufficient capacity in order to be able to identify and respond to water security challenges, to ensure that water does not become a source for conflict but rather promotes unity for greater economic and social development.

A key publication on global water security has been the Intelligence Community Assessment undertaken by the United States Government (ICA 2012). It provides a dispassionate analysis of the global water security situation and identifies a number of transboundary river basins in which water security is projected to become a major concern in the coming decade or so. In particular, the following findings of the report are eye-opening and have relevance to food and energy security:

- During the next 10 years, water problems will contribute to instability in many developing countries.
- Water shortages, poor water quality, and floods when combined with poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions will contribute to social disruptions that can result in state failure.
- As water shortages become more acute beyond the next 10 years, water in shared basins will increasingly be used as leverage for addressing other, political conflicts. It is also likely that water may be used as a weapon or to further terrorist objectives.
- Depletion of groundwater supplies in next 10 years in some areas will pose a risk to both national and global food markets. This is directly linked to poor water management and inadequate policies.
- The greatest potential for relief from water scarcity is through reduction in water usage by agriculture.

The last point highlights the correlation between water security and food security. Economic development, which relies on sustainable and sufficient energy resource, is equally linked to

Box 1: Dimensions of Water Security (reproduced from UN-Water 2013)

The discourse on water security in recent years contains a number of common, key elements to water security. Below is a summary of the core elements necessary to achieving and maintaining water security:

- Access to safe and sufficient drinking water at an affordable cost in order to meet basic needs, which includes sanitation and hygiene (cf. United Nations General Assembly 2010), and the safeguarding of health and wellbeing;
- Protection of livelihoods, human rights, and cultural and recreational values;
- Preservation and protection of ecosystems in water allocation and management systems in order to maintain their ability to deliver and sustain the functioning of essential ecosystem services;
- Water supplies for socio-economic development and activities (such as energy, transport, industry, tourism);
- Collection and treatment of used water to protect human life and the environment from pollution;
- Collaborative approaches to transboundary water resources management within and between countries to promote freshwater sustainability and cooperation;
- The ability to cope with uncertainties and risks of water-related hazards, such as floods, droughts and pollution, among others; and,
- Good governance and accountability, and the due consideration of the interests of all stakeholders through: appropriate and effective legal regimes; transparent, participatory and accountable institutions; properly planned, operated and maintained infrastructure; and capacity development.

water security. Many have argued that the Water-Food-Energy security nexus is an important dimension of solving the economic development and poverty reduction puzzle.

The Water-Food-Energy "Nexus" as a solution

The concept of the Water-Food-Energy (W-F-E) nexus was presented at the Bonn 2011 Conference "The Water, Energy and Food Security Nexus - Solutions for the Green Economy" (16–18 November 2011). It is defined as 'an approach that integrates management and governance across sectors and scales' and which *inter alia* aims at resource use efficiency and greater policy coherence (Hoff 2011). It is argued that a reduction of negative economic, social and environmental externalities in economic planning can lead to a greater overall resource use efficiency and provide additional benefits in the form of securing human rights to water and food. Successfully achieving the implementation of the nexus approach requires breaking down traditional silos in which policymaking takes place.

The nexus approach has a number of corollary benefits. It fits well with the approaches for achieving human security – through water and food as human rights – and political security – through economic growth and stability. Such integrated approaches can also catalyze greater regional integration around shared resources; for example, in transboundary basins cooperation around water resources becomes more enhanced when it is linked to also sharing energy through hydropower generation. The nexus approach also fits well with both mitigation and adaptation strategies under intense discussion at the climate change dialogue. Coupling water, food and energy security allows climate-change negotiators to see beyond narrow benefits and allow for greater integration into national economic policies.

Finally, the W-F-E nexus is also relevant in disaster relief situations as well as post-conflict reconstruction situations. Both natural disasters and armed conflict often lead to refugees and internally displaced persons, who in turn are in dire need to receive adequate food, water and shelter. Provisioning of these services requires availability of adequate energy. It thus becomes advisable that recovery and relief programmes in these situations follow a nexus approach.

Achieving the W-F-E security nexus in drylands is easier said than done. In part, because it is a new concept and typically government agencies and department are not designed to work across their specific domains, its implementation would offer new challenges. In order to successfully implement the W-F-E nexus, the following three elements are essential.

First, the W-F-E nexus must be connected and integrated into the national economic development narrative. Such integration must start at the top political level and trickle down to line departments and agencies; an entry point could be the ongoing planning around Sustainable Development Goals (SDGs) as part of the post-2015 development agenda. It must also be coupled with mobilizing financial resources and allocating investments within national budgets. It may also be required to formulate an enabling environment in which investments from the private sector are solicited in order to achieve the nexus.

Second, the discussions around the W-F-E nexus must be couched in terms of its human and social dimensions. The obvious links are to food and water as a human right, and the role these would play in achieving human health and wellbeing. A not so obvious links are to job creation and livelihood security, which can be achieved and are bound to be politically attractive. This *inter alia* means that countries must build human and technological capacity to achieve security around the W-F-E nexus. This capacity development can become an agent of change in the context of understanding and overcoming cross-sectoral divergences.

Third, the W-F-E nexus must be integrated into regional dialogues, most notably in situation where water is a shared resource across national and sub-national boundaries. Integrated regional dialogues can boost transboundary trade and cooperation and reduce transaction costs for achieving cooperation. It can also help improve institutions dealing with transboundary governance and overall policy coherence.

In conclusion, water security in drylands is closely linked to food and energy security. Arguably, these very closely linked domains cannot be planned in isolation. For drylands to overcome their intrinsic resource scarcity, cross-linked policies utilizing the W-F-E approaches offer a way out.

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Climate change and food security in the Arab region

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Abstract

Water is the most important resource for agricultural development in the region of Nile Valley and Red Sea. Climate change has posed an additional threat to water availability in the region because of the increase in temperature that is increasing evapotranspiration and thus elevating the demand for water. The Nile valley and Delta area, which is the major irrigated agricultural area in the region, is irrigated by surface irrigation. Water use efficiency is as low as 45-50% in several cases. Fragmentation of land ownership is adding to the management problems and resulting in more waste in water use. Due to the need of additional land to produce more food to feed the population, land reclamation seems to be the only solution. The reclaimed land will depend on rain fall in some countries but will need more dependence on the surface water as well as underground water in other countries that are within the hyper arid zones. The situation may get worse under climate change conditions. Saving agricultural water is therefore essential. The Egyptian Sustainable Agricultural Strategy has included several measures to adapt to climate change and increase water use efficiency including the reduction of area cultivated with rice, improving farming systems for animal husbandry, introducing the cropping pattern with improved agricultural extension service, improving on-farm water management in the old lands, concentrating on the agro-industrial complexes in the new land-reclamation projects, improving the human resources working in agricultural sector, and increasing the public awareness on climate change through integrated programs involving private and public sectors. One of the most important issues in this effort is the national program for improving on-farm water management. The program is based on improving soil conditions through laser leveling and changing the old surface irrigation system to modern water saving systems that suit different crops. Besides, the program will help in adapting to possible climate changes. Several policies will be changed to facilitate the implementation of the program. The availability of reliable and timely information is a cornerstone for adaptation to climate change. Establishment of a Regional Center for Climate Change Information is essential for promoting development and use of adaptation and mitigation strategies in the Nile Valley, Red Sea and North Africa region.

Introduction and background

The issue of climate change has been increasingly discussed by both scientists and industry since the early 1990s. The comprehensive package of instructional resources is designed to help peoples to develop an understanding of the concepts of climate change and the skills to deal with the issues involved. Climate change is a natural process but recent trends related to climate change are alarming mainly due to anthropogenic reasons. Climate change has already affected people, their livelihoods and ecosystems and presents a great development challenge for the global community in general and for the poor people in developing countries in particular.

The level of greenhouse gases (GHGs) - mainly carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) - have been rapidly increasing after the industrial revolution. The increased level of GHGs has created a greenhouse effect which subsequently altered precipitation patterns and global temperatures around the world. Impacts have been witnessed in several areas due to change in precipitation and temperature. The impact areas include, among others, agriculture, forestry, water resources, biodiversity, desertification, human health, and ecosystems goods and services globally. Research has revealed that rate and extent of climate change effects have increased significantly over the years with the increasing weather variability and extreme events.

Clear impacts from climate change are being witnessed in agriculture. Impacts are both positive as well as negative. They are, however dependent on latitude, altitude and type of crop. There have been noticeable impacts on plant production, insect, disease and weed dynamics, soil properties and microbial compositions in farming systems (Eid and El-Marsafawy 2002). According to IPCC (2007a), a temperature change in tropical areas has in general a negative impact on food production and it is estimated that food production within South Asia will decrease by about 30% by 2050. Although cause and effect relations of climate change and agriculture are seen in many forms and extent, assessment of those relations and effects of climate change on agriculture and the impact of agriculture (both conventional and organic) on climate change are not properly documented. Understanding of this nexus is vital not only to improve the agricultural sector productivity but it is also important to positively contribute to the environmental management regime at large.

The climate change and agriculture are closely linked and interdependent. Compared to conventional agriculture, organic agriculture is reported to be more efficient and effective in reducing GHGs emission, mainly due to the less use of chemical fertilizers and fossil fuel. Organic agriculture also was reported to be climate change resilient farming system as it promotes the proper management of soil, water, biodiversity and local knowledge, thereby acting as a good option for adaptation to climate change. But, due to lack of proper research, the contribution of organic agriculture for climate change adaptation and mitigation is yet to be known in many areas. It is argued that organic agriculture positively contributes to offset negative impacts of climate change, but there is inadequate systematic data to substantiate this fact.

At the same time, extreme weather events such as droughts, floods, storms and hurricanes, and spells of extremely high or low temperatures are becoming more frequent and more severe. Current observations indicate increased occurrence of such events, and model predictions suggest that this trend will continue. Famines, as pointed out by Sen (1981), are really man-made disasters that are the result of climatic risks (e.g., prolonged periods of low rainfall and high temperatures) and human failures to respond to resulting declines in food production and increased malnutrition. Humanitarian disasters caused by weather related shocks are therefore likely to increase in number and severity.

Dasgupta *et al.* (2009) reported that the potential impact of increasing frequency and severity of storm surges is evident in most of the countries in the MENA region (Fig. 1).

Climate change may affect food systems in several ways ranging from direct effects on crop production (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure. The impacts of climate change on agriculture activities have been shown to be significant for low input farming systems in developing countries in Africa (Rosenzweig and Parry 1994; McGuigan *et al.* 2002). Furthermore, tropical regions in developing countries are usually

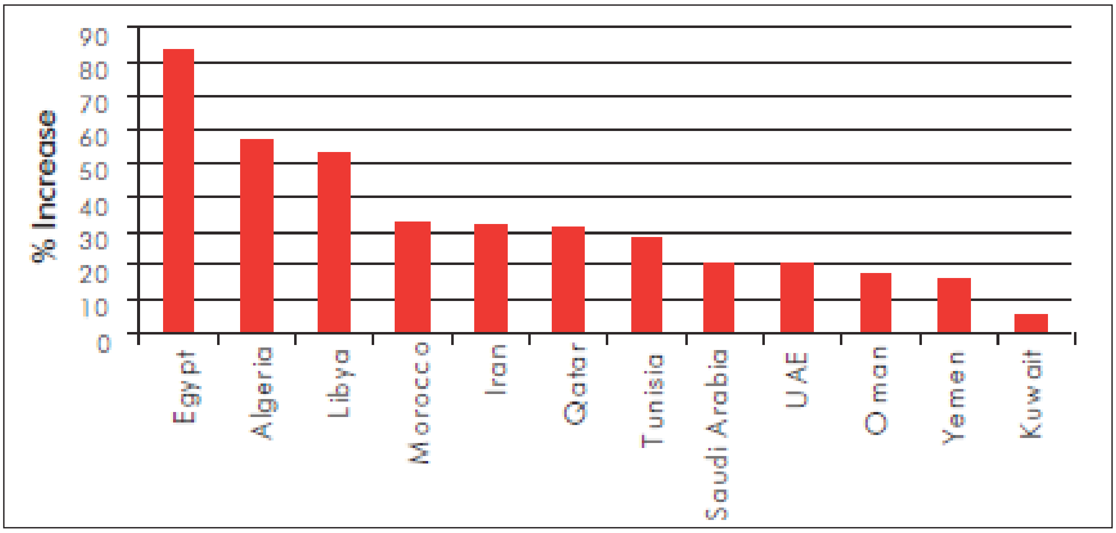

Figure 1: Expected increase of storm surges in some countries as affected by climate change.

characterized by poor and marginal soils that cover extensive areas, making them unusable for agriculture, making the developing countries particularly vulnerable to potential damage from environmental changes (Mendelsohn and Dinar 1999). The expected sea level rise due to climate change will affect several countries in MENA region. Figure 2 shows that the area lost to sea level rise would range between less than one percent of the total country area in Algeria to 12 percent in case of Qatar. But the impact on national economy is different, where Egypt will be most affected due to its dependence on agriculture activities in the Nile Delta (Fig. 3).

Abou Hadid (2009) indicated that food security in the Arab world and Nile valley has experienced a long history of environmental and socio-economic pressures. The dominant arid conditions, limited water resources, erratic cropping patterns, and low level of technology and knowledge are the main factors presently affecting food production systems in the region. Most recent assessments have concluded that arid and semi-arid regions are highly vulnerable to climate

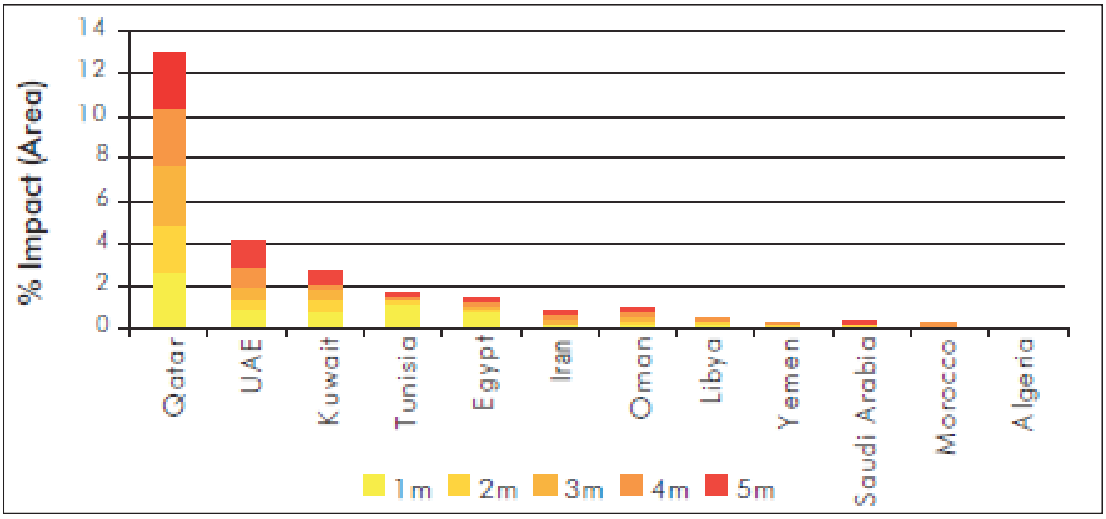

Figure 2: A comparison of persentage impacts of sea level rise on land areas of Arab Countris (after Dasgupta *et al.* 2007).

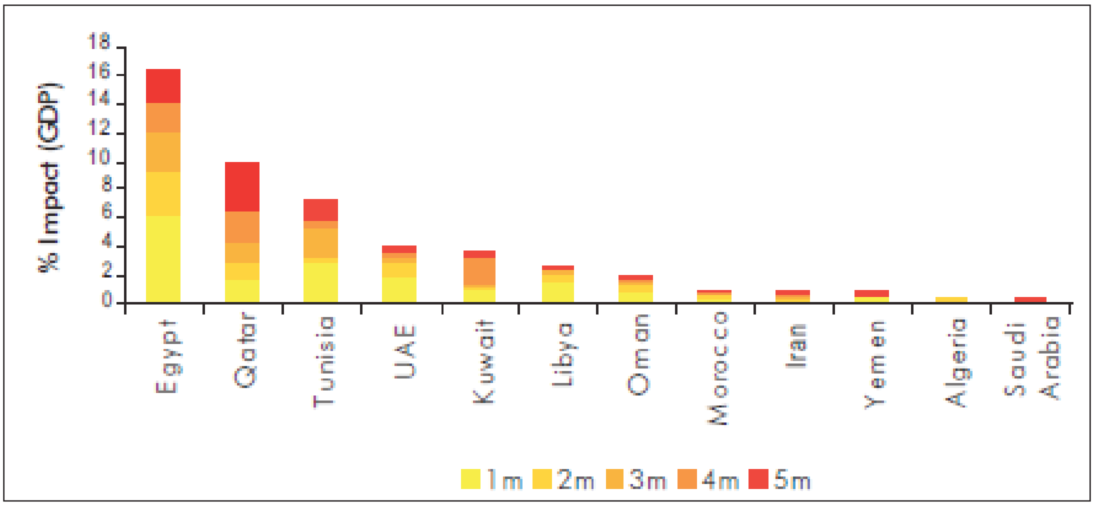

Figure 3: A comparison of percentage impact of sea level rise on the GDP of Arab Countris (after Dasgupta *et al* 2007).

change (IPCC 2007a). On the other hand, at a high level conference of the Food and Agriculture Organization (FAO) held in Rome in June 2008, the delegates asserted that agriculture is not only a fundamental human activity at risk from climate change, it is a major driver of environmental and climate change itself. The projected climatic changes will be among the most important challenges for agriculture in the twenty-first century, especially for developing countries and arid regions (IPCC 2007a).

By the end of the 21st century, the Arab region will face an increase of 2 to 5.5ºC in the surface temperature. This increase will be coupled with a projected decrease in precipitation up to 20%. These projected changes will lead to shorter winters and dryer and hotter summers, more frequent heat wave occurrence, and more occurrence of variability and extreme weather events (IPCC 2007b).

Climate change could exacerbate the food security issues that North Africa and Nile valley region already faces. Egypt's report to the United Nations Framework Convention on Climate Change (UNFCCC) states that "climate change may bring about substantial reductions in the national grain production." Grain is only one of Egypt's food sources endangered by unmitigated climate change. Even without climate change, by 2020 Egypt is projected to import 300-360 thousand metric tons of fish, which is a third of its projected domestic production. However, climate change could drastically increase Egypt's trade imbalance in fish products while simultaneously tightening the global fish market. As the sea level rises, salt water will infiltrate the North Egyptian lakes where 60% of Egypt's fisheries are located. The situation in other countries of the region is similar, and due to political and socio-economic conditions, could even be worse.

Abou Hadid (2009) reported that impacts of climate change on agricultural activities in term of yield reduction and increasing of water needs have been studied for the last two decades in Egypt. Climate change could decrease the national production of rice *(Oryza sativa*) by 11 % and soybeans (*Glycine max*) by 28 % by the year of 2050, compared with their production under current conditions. It could reduce national maize *(Zea mays*) and sorghum (*Sorghum* bicolor) production by about 19 %, and wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.) grain production by 18%. Cotton (*Gossypium* spp.) seed yield would increase by 17 % if the temperature increased by 2°C and by 31% with a 4°C increase. By the year 2050, climate change could increase water needs by up to 16 % for summer crops and more than 2.5% for wheat crop.

Water is the most important resource for agricultural development in the region of Nile Valley and Red Sea (Abou Hadid 2010). Climate change has posed an additional threat to water availability in the region because of increased evapotranspiration which would elevate the level of demand for water. The Nile Valley and Delta egion, which constitute the major irrigated agricultural area in the region, is irrigated by surface irrigation. Water use efficiency in several cases is as low as 45-50%. Fragmentation of land holding is adding to the management problems and raising the waste in the water use. Due to the need of additional land to produce more food to feed the population, land reclamation seems to be the only solution. The reclaimed land will depend on rain fall in some countries but will need more surface water as well as underground water in other countries that are within the hyper arid zones. The situation may get worse under climate change conditions. Saving agricultural water is therefore a must.

The objective of this paper is to stress upon the need to establish a Regional Climate Change Information Center. Table 1 indicates that several countries of the region have submitted the first national communication between the year 1997 and 2007. However, some of the countries did not issue the second national communication yet. One of the reasons for the delay could be the lack of availability of information and therefore, the establishment of a Climate Change Network and the Climate Change Information Center for the region could help keeping the region updated on this serious issue.

Table 1: The date of publishing the first national communication in Arab countries. (Adapted from http://unfccc.int/national_reports/non-annex_i_natccm/items/2979.php)

Country	First national communication	Country	First national communication	Country	First national communication
Algeria	2001	Lebanon	1999	Sudan	2003
Bahrain	2005	Mauritania	2002	Tunisia	2001
Egypt	1999	Morocco	2001	United Arab Emirates	2007
Jordan	1997	Saudi Arabia	2005	Yemen	2001

Impact of climate change and adaptation measures

The Egyptian sustainable agricultural strategy has included several measures to adapt to climate change and to increase water use efficiency. These include the reduction of area cultivated with rice, improving farming systems for animal husbandry, introducing the cropping pattern with improved agricultural extension service, improving on-farm water management in the old lands, concentrating on the agro-industrial complexes in the new-land reclamation projects, improving the capacity building of human resources in agricultural sector, and increasing the public awareness on climate change through integrated programs involving private and public sectors.

One of the most important issues in this effort is the national program for improving on-farm water management. The program started in 2009 and the first phase will finish by 2017 and the second phase by 2030. The program depends on improving the soil conditions through laser leveling and changing the old surface irrigation system to modern water saving systems that suit different crops. Besides, the program will help in adapting to possible climate change. The program will also create new job opportunities for about three million families and control the waterborne infectious diseases by covering the branch canals and limiting human direct contact with untreated surface water. Future climatic changes will lead to reduction in productivity of crops, increasing crop water needs and decreasing crop water productivity. To cope with these adverse impacts of climate change, more adaptation strategies will be evaluated to reduce vulnerability and realize opportunities associated with climate change effects and hazards. There are numerous examples of successful adaptations that would apply to climate change risks and opportunities. Substantial reductions in climate change damages can be achieved, especially in the most vulnerable regions, through timely deployment of adaptation measures.

Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. This omission in the design and implementation of many recent and current development initiatives results in unnecessary additional losses to life, well-being, and short and longer terms investments. Enhancement of adaptive capacity is necessary to reduce vulnerability. Activities required for the enhancement of adaptive capacity are essentially equivalent to those that promote sustainable development and equity (IPCC 2001; Abou Hadid *et al* 2003; Leary *et al* 2007).

Economics of climate change impact

According to Stern (2006), the costs of taking action are not evenly distributed across sectors or around the world. Even if the rich world takes on responsibility for absolute cuts in emissions of 60-80% by 2050, developing countries must take significant action too. But developing countries should not be required to bear the full costs of this action alone, and they will not have to. Carbon markets in rich countries are already beginning to deliver flows of finance to support low-carbon development, including through the Clean Development Mechanism. A change in these flows is now required to support action on the scale required. Action on climate change will also create significant business opportunities, as new markets are created in low-carbon energy technologies and other low-carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly. The World does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. Indeed, ignoring climate change will eventually damage economic growth. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries.

Proposal for a Climate Change Information Center

The need for exchanging information and increasing awareness on climate change issue is a major consideration all over the Red Sea, Nile Valley, Near East, and North Africa region. Therefore, it was proposed to create a regional Climate Change Information Center (CCIC) in the region that will be a focal point for collecting data, generating information, and disseminating knowledge to stakeholders in the region. Several legislations and policies may have to change to facilitate the implementation of greenhouse gases reduction and other related programs. The proposed CCIC, which will be established in cooperation with the stakeholders of the agricultural sector, will help realize these objectives by providing networking opportunities within each country and on the regional level. The Center in Egypt that was created within the activities of the Arid Lands Agricultural Studies and Research Institute (ALARI) of Ain Shams University and linked to a similar Center in the Agricultural Research Center of Egypt could be easily transformed and expanded to act as a Regional Climate Change Information Center for south Mediterranean region and Nile Valley and Red Sea region.

The objectives of the Center will be to:

- Develop an integrated approach of good agricultural management for mitigating the negative impacts of the future climate change on agriculture.
- Analyze the effect of different scenarios of higher temperatures on crop productivity under different agro-climatic zones.
- Create an inventory of different crop varieties and cultivars, and animal genetic lines vulnerable to possible climate change for the region.
- Integrate the negative impact of climate change on various components of agricultural sector (plant and animal production, water use, diseases and insects) to update assessment of the negative impacts on net income of the agricultural sector.
- Facilitate the conduct of future climate change economic studies for the region in cooperation with the relevant institutes undertaking agricultural and environmental research.
- Study the impact of climate change on crop combinations and determine the crop rotation that could achieve better profitability for farms under different agro- climatic zones.
- Conduct training and knowledge transfer programs about climate change phenomena and its impacts on agriculture sector.
- Produce bulletins and other information material on the best possible agricultural operations under future conditions to reduce the negative impact of climate change on crop productivity.

The proposed regional CCIC will undertake innovative actions on the regional basis through strengthening and promoting reforms in policies and investments that indirectly reduce vulnerability to climate change (e.g. improved water demand management, agriculture diversification through cereal production improvement, and supply chain development); or that promote reduction of GHGs emissions. It will develop innovative response to climate change. The CCIC will develop new types of analytical services to assist stakeholders to better evaluate magnitude and spread of the impact of climate change, engage in support of new technologies for both mitigation and adaptation, and support innovative mechanisms to reduce climate risks (e.g. insurance, contingent financing, etc.).

Climate change being a serious and complex challenge for any single actor to handle in isolation, CCIC will actively seek partnerships with the relevant institutions in all countries of the region.

CCIC will undertake high-level consultations with its stakeholders to agree on priorities for action on climate change, and will seek collaborations with regional and international organizations and funding agencies. It will also assist in the preparation of different reports and country obligation to international protocols. It will facilitate the update of methodologies of data collection and handling. It will also assist in the identification of research gaps and prioritize study needs for climate change issues in the agricultural sector. The data and information will be circulated through a central database available to the beneficiaries in several forms for application such as digital tabular data, digital maps, graphs and demonstrative formats, and text reports. CCIC will establish an interactive high speed web site to facilitate data sharing and assure its availability.

Following sources at national and regional institutes and organizations will be used to obtain needed information for CCIC: Ministry of Agriculture and Ministry of Environment, economic sector and organizations responsible for mobilization and mass surveys, agricultural extension systems, Ministry of Irrigation and Water Resources, Ministry of International Cooperation, organization for planning and administration, national and international development projects, international interested organizations and donors, coasts protection organization, meteorological authority, and geographical survey authority. The cooperation between these authorities and the Center will be specified in the letters of agreements that describe the duties and rights of each partner to exchange information between the Center and interested and to protect the intellectual property rights. The Center is expected to make available data and information related to the following issues:

- Classification of cultivated land (accurate and detailed classification in the form of digital maps or satellites images).
- Irrigation sources (type and capacity).
- Cropped area under different crops (digital data or satellite images).
- Productivity of different crops (both main and the secondary crops).
- Planting and harvesting dates.
- Use of irrigation water and irrigation systems.
- Fertilizer and pesticide use.
- Extent of morbidity and insect damages.
- Limitations of energy resources and machines used in the agricultural production.
- Environmental problems (sea-level rise, ground water depletion, land and water salinity, water pollution).
- Greenhouse gas emission.
- Influence of climate change on agricultural sector.
- Population in rural areas and agricultural employment.
- Agricultural production economics.
- Global indicators of agricultural production.
- Data related to previous global and national climate change studies (DSSAT simulation model and other models will be used to achieve some of the previous issues)

It is suggested that the center may consist of 4 main working groups in addition to administrative and service components:

- Programming and technical support group: concerned with establishing, operating and maintaining central data base as well as associated applied programs.

- Data collection and handling group: concerned with inserting data into central data base, data correction and disseminating data to the stakeholders.
- Research monitoring group: to collect the research activities, reports, and research articles from different sources, and prepare metadata files and archives.
- Science supporting group: determine kind of data required for conducting studies, setting priorities, applying various studies, offering technical and scientific consultations associated with climate change research.

The proposed center could assist the member countries and institutions in the following fields:

1. *Emissions trading*: Expanding and linking the growing number of emissions trading schemes around the world to promote cost-effective reductions in emissions and to bring forward action in developing countries. Synchronizing action to obtain financial and technical support for the processes of the transition to low-carbon development paths.

2. *Technology cooperation*: Informal co-ordination as well as formal agreements to boost the effectiveness of investments in innovation around the world. Globally, support for energy R&D could increase, and the increasing support for the deployment of new low-carbon technologies is available and needs to be used for the region.

3. *Action to reduce deforestation*: The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large scale international pilot programs to explore the best ways to do this could get underway in a timely manner.

4. *Adaptation:* The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honor their pledges to increase support through overseas development assistance. International funding should also support improved regional information on climate change impacts, and the research on developing new crop varieties that will be more resilient to drought and flood.

Avoiding the risks of climate change

The risks to agriculture associated with climate change are a result of the strong relationship between agriculture and climate system, plus the high reliance of agriculture system on the natural resources. The projected increase in temperature is perceived to increase the gap between water resources and demands, decrease the overall agriculture productivity, and increase the competition between various sectors for the natural resources. The effects of sea level rise on the coast of the Nile Delta would reduce the area under cultivation. The impact of climate change is most likely to hit the rural communities in the country severely, due to the fragile socioeconomics of the rural people.

The vulnerability of the agriculture in the region to climate change is mainly attributed to both biophysical and socioeconomic factors. Changes in crop productivity are mainly attributed to the projected temperature increase, crop-water stress, pests and diseases. It will be a challenge for the agricultural sector in the future to strike a balance between reducing the use of pesticides and appropriate pest management practices. The intensity of the heat and cold waves increased in the past twenty years will cause several harmful impacts on crop productivity, especially for fruits and vegetables.

Projected future temperature rises under climate change conditions are likely to increase crop-water requirements thereby directly decreasing crop water use efficiency and increase the irrigation demands of the agriculture sector. Crop water requirements of the important strategic crops in Egypt are going to increase under all IPCC SRES socioeconomic scenarios of climate change by a range of 5 to 13 % by 2100s and raise the vulnerability of the on-farm irrigation system. Using different combinations of improved surface irrigation systems and applying deficit irrigation could improve the efficiency of surface irrigation system.

Current evidence shows that increase in temperature is causing harmful heat stress impacts on animal productivity; new animal diseases have emerged in North Africa, which have strong negative impacts on livestock production. Possible increase in the transfer of diseases from animals to humans would be another threat. The availability of fodders may decrease. The most likely adaptation options for livestock include improving the current low productivity cattle and buffalos breeds and developing feeding programs better adapted for warmer climate conditions.

Climate change induced increase in sea temperature would cause a shift in fish distribution northwards and deeper into water. Aquaculture projects may suffer from water shortages. The increased salinity of water in the coastal lakes may gradually reduce the existence of fresh water fish and increase the portion of saline water fish which is more sensitive to environmental changes. There is no clear adaptation options defined for this important sector. Further studies on the impacts, vulnerability, and adaptation to climate change are still needed, but the lack of availability of information, data, and networks creates a strong obstacle in this direction.

General remarks and recommendations

Designing and applying a national adaptation strategy for the agriculture sector is facing serious limitations of lack of scientific information and policy perceptions, poor adaptive capacity of the rural community, lack of financial support, and absence of the appropriate institutional frameworks and linkages. The following consideration could be included to enhance the planning of adaptation and mitigation strategies for agricultural sector under Egyptian conditions: improve the scientific capacity, use the bottom up approach of adaptation planning, developing community-based measures through stakeholders' involvement in adaptation planning, increase the public awareness about climate change and its relation to human systems, and improve adaptive capacity of the community.

The recommended priorities of the agriculture sector in the adaptation to climate change could be summarized as follows:

- Conduct a national program for improving the cropping pattern and calendar adapted to the projected climate changes. This program should include developing and testing heat, water stress, salinity and pests and disease tolerant cultivars of the major crops. Dissemination of the results to the farmers should be one of the important objectives of this program.

- Implement nation-wide project targeting improving the on-farm irrigation system in order to tackle the problem of expected increase in the pressure on water availability, and higher irrigation demands under climate change conditions.
- Assure sustainable adaptation funds and climate hazards insurance systems as a part of adaptation planning.
- Establish a strong regional information dissemination system regarding climate change and its impacts on agriculture targeting all stakeholders in order to assist them in developing appropriate adaptation measures. This may start by establishing a regional network for climate change among all the countries of the region, supported as much as possible by the international organizations involved in the issues of climate change, to catalyze multi-disciplinary action for climate change and to provide the needed mechanism for sharing climate change information.

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Renewable energy for rural development in drylands

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Abstract

New types of rural development models that exploit renewable energy sources have attracted a great deal of attention in various parts of the world, largely because of concerns about climate change and the price and supply of oil. Particularly in rural areas of developing countries, access to modern forms of energy such as electricity and oil is essential to improve the quality of life of villagers. The use of renewable energy and new technologies is expected to contribute to poverty alleviation by creating new businesses and job opportunities, to better education by providing electricity to schools, and to improvement of health conditions by replacing traditional stoves that emit large amounts of air pollutants. Reduced use of wood fuel will also contribute to prevention of overcutting, which is a cause of desertification in drylands. Rapid innovation and reduced costs in renewable energy technologies have expanded the potential of rural development projects. In some projects, renewable energy sources such as wind, solar, plant biomass, and livestock manure have been used in villages. In addition, energy-saving appliances such as solar cookers, solar water heaters, and high-efficiency furnaces and stoves have been introduced in many areas. Electricity generated by wind, solar, micro-hydro, and biomass power plants has been used for lighting, heating, cooking, and other purposes. In some areas with serious water shortages, seawater or brackish water has been desalinated by electricity generated from renewable energy sources; the desalinated water is then used for drinking water, agricultural irrigation, and other purposes. Innovative thinking is required to integrate the exploitation of renewable energy sources and efficient and systematic use of energy to achieve sustainable rural development.

1. Introduction

Energy is crucial for rural life and development. Developing countries are facing two crucial and related problems in the energy sector (Barnes and Floor 1996). The first is widespread inefficient production and the use of traditional energy sources, such as wood and agricultural residues, which pose economic, environmental, and health threats. The second is the highly uneven distribution and use of modern energy sources, such as electricity, petroleum products, and liquefied or compressed natural gas, which pose important economic, equity, and quality of life issues. In this context, the *Future We Want*, an outcome document adopted at the United Nations Conference on Sustainable Development (Rio+20) in Rio de Janeiro in 2012, states that “We recognize the critical role energy plays in the development process, as access to sustainable modern energy services contributes to poverty eradication, saves lives, improves health and helps provide basic human needs” (UN 2012).

Although there are many definitions and measures of energy poverty (Nussbaumer et al. 2012), generally, lack of access to modern energy services is called energy poverty. One definition of energy services is household access to electricity and clean cooking facilities (e.g., fuels and stoves that do not cause air pollution in houses) (http://www.iea.org/topics/energypoverty/).

According to statistics of the International Energy Agency (IEA 2010), the number of people in energy poverty defined by lack of access to electricity in 2009 is 1.441 billion, and the number of people relying on the traditional use of biomass for cooking is 2.679 billion (Table 1). These are people in energy poverty, and most live in developing countries.

Table 1: Number of people (millions) without access to electricity and reliant on traditional use of biomass, 2009

	Number of people lacking access to electricity	**Number of people reliant on traditional use of biomass for cooking**
Africa	587	657
Sub-Saharan Africa	585	653
Developing Asia	799	1937
China	8	423
India	404	855
Other Asia	387	659
Latin America	31	85
Developing countries*	1438	2679
World**	1441	2679

*Includes Middle Eastern countries. **Includes Organisation for Economic Co-operation and Development (OECD) and transition economies. Source: IEA (2010)

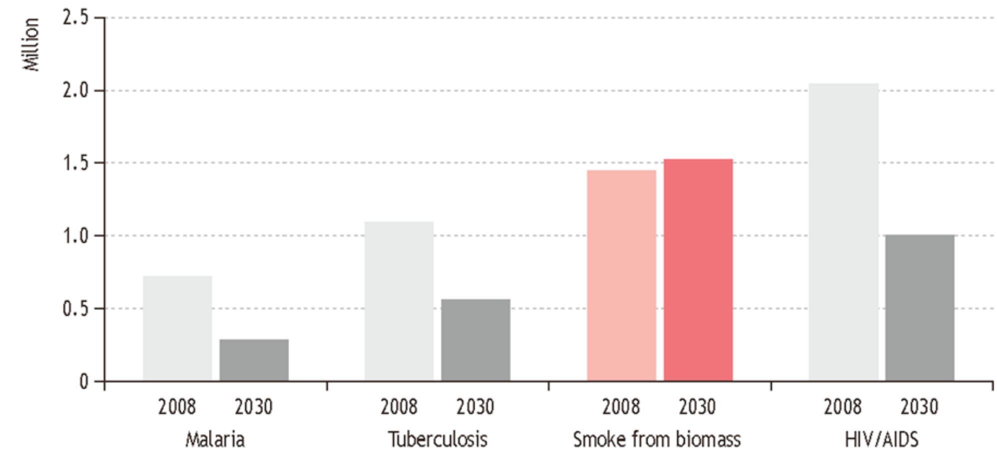
Table 2 shows that 85% of people who lack access to electricity live in rural areas (Kaygusuz 2012). Furthermore, the projections suggest the number without said access will increase, especially in Sub-Saharan Africa.

Table 2: Number of people (millions) without access to electricity by region

	2009			**2030**
	Rural	**Urban**	**Total**	**Total**
Africa	466	121	857	644
Sub-Saharan Africa	465	120	585	640
Developing Asia	716	82	799	650
China	8	0	8	2
India	380	23	404	342
Other Asia	328	59	387	307
Latin America	27	4	31	16
Developing countries*	1229	210	1438	1350
World**	1232	210	1441	1352

*Includes Middle Eastern countries. **Includes OECD and transition economies. Source: Kaygusuz (2012)

The traditional use of biomass is not only inconvenient, but also bad for health. Figure 1 shows the number of premature deaths per year in 2008 and 2030. The number of deaths by smoke from biomass is estimated around 1.4 million for 2008, and larger for 2030. Household air pollution from the use of biomass in inefficient stoves would cause over 1.5 million premature deaths annually by 2030. This means that the lack of access to clean energy is not just inconvenient, but may also lead to health problems.



Sources: Mathers and Loncar (2006); WHO (2008); Smith *et al.*, (2004); WHO (2004); and IEA analysis.

Figure 1: Household air pollution from use of biomass in inefficient stoves. (Source: IEA (2010))

In light of these circumstances, the United Nations and the international community have repeatedly made commitments to reducing energy poverty. There have been commitments related to reduction of energy poverty in the Millennium Development Goals (MDGs) in 2000 toward the target year 2015, followed by the Johannesburg Plan of Implementation adopted at the World Summit on Sustainable Development (WSSD) in 2002, and *The Future We Want* adopted in 2012. In that document, energy is covered in Section 125, which includes the statement "We commit to facilitate support for access to these services by 1.4 billion people worldwide who are currently without these services."

2. Energy access and rural development

It is widely recognized that access to modern energy services is a key element for rural development (e.g., Cabraal *et al.* 2005; Kaygsuz 2011).

It is well known that there is a relationship between income by GNP per person and the use of traditional energy by percent biomass of total energy used (e.g., World Bank 1996). Rich people use less biomass, whereas poor people depend on it. This relationship may show that increased access to modern energy services facilitates rural development. For example, access to modern energy services may increase income, if it is used productively.

The World Bank (2006) showed levels of electricity access in selected Sub-Saharan African countries. For example, the population of Ethiopia is 79.1 million and only 12% of people have access to electricity, only 2% in rural areas. In other countries of this region, the figure is usually less than 10%. Given these facts, it is urgently needed to bring rural areas out of energy poverty.

Table 3: Time spent collecting wood for fuel

Quartile of per capita income	Distance to collect fuel wood (km)	Duration of collection per trip (hrs)	Number of trips per month	Average time per month spent (hrs)	Share of total expenditures devoted to energy (%)
1	1.2	2.9	4.4	12.8	9.8
2	1.2	2.9	3.4	9.9	8.6
3	1.1	2.7	3.1	8.2	10.2
4	1.0	2.8	2.8	8.0	10.4
Total	1.1	2.8	3.5	9.9	9.7

Note: Based on 1899 households reporting non-zero wood fuel collection time. Source: Christiaensen and Heltberg (2012)

Table 3 shows the time spent collecting wood fuel in Chinese rural villages (Christiaensen and Heltberg 2012), divided by quartile of per capita income. The average time per month was close to 10 hours, a very long time, even more for the poor. Christiaensen and Heltberg (2012) also reported medical symptoms or behavior attributable to dirty fuel use. The use of dirty fuel such as coal, wood, and crop residues in cooking is more frequent than the median result in people more likely to suffer from coughing and other respiratory ill-health, as well as increased medical expenses.

Overexploitation of wood fuel is one of the primary causes of land degradation or desertification, because this causes long-term reduction of vegetation cover by overcutting of wood. Thus, if wood is replaced by another energy source, it may mitigate land degradation and desertification.

Under these circumstances, the UN and international community have taken initiatives toward reducing energy poverty. For example, the World Bank made a commitment to extend modern energy supplies to unserved populations, promote sustainable supply and use of biofuels, and introduce new renewable energy technologies (World Bank 2006). The year 2012 was designated by the UN as the International Year of Sustainable Energy for All, a global initiative led by UN Secretary-General Ban Ki-moon, which has three objectives: providing universal access to modern energy services; doubling the global rate of improvement in energy efficiency; and doubling the share of renewable energy in the global energy mix by 2030. The appropriate energy mix to meet development goals is supposed to be achieved through increased use of renewable energy sources and other low-emission technologies, more efficient energy use, greater reliance on advanced energy technologies including cleaner fossil fuel, and sustainable use of traditional energy sources. (http://www.sustainableenergyforall.org/)

3. Rural development involving renewable energy

3.1 Types of rural development projects

Renewable energy can be defined as energy derived from natural processes (e.g., sunlight and wind) that are replenished more rapidly than they are consumed. Solar, wind, geothermal, hydro, and certain forms of biomass are common sources of renewable energy (http://www.iea.org/aboutus/faqs/renewableenergy/). New types of rural development models that exploit renewable energy sources have attracted a great deal of attention in various parts of the world, largely because of concerns about climate change and the price and supply of oil.

Table 4 shows household energy-use patterns in India (Khandker et al. 2010). In urban areas, most people use modern energy sources such as kerosene, LPG and electricity. However, in rural areas, people still depend on traditional sources such as wood, livestock dung and crop residue. As described above, such a situation of energy poverty is linked to hard work in collecting wood, health problems and others.

Table 4: Household energy-use patterns in India

Energy use	Traditional source				Modern source			
	Wood fuel	Dung	Crop residue	Coal/ charcoal	Kerosene	LPG	Electricity	All sources
Rural areas (N=22,538)								
Household users (%)	89.2	55.1	21.7	4.8	90.8	16.6	56.5	100.0
Quantity used*	131.6	73.8	28.8	3.9	2.7	1.7	36.0	-
Energy used (kg OE/ month)	49.3	25.0	10.6	2.4	2.2	1.8	3.0	94.3
Energy expenditure (Rs**/ mo nth)	191.8	77.1	43.2	7.9	39.6	36.8	80.3	476.7
Share in total household energy use (%)	56.3	22.6	6.8	2.5	3.5	3.6	4.7	100.0
Urban areas (N=12,325)								
Household users (%)	34.6	13.4	1.8	6.6	54.2	71.4	94.0	100.0
Quantity used*	31.5	9.0	1.2	4.3	2.6	9.0	87.5	-
Energy used (kg OE/ month)	11.6	3.0	0.4	2.6	2.1	9.3	7.3	36.2
Energy expenditure (Rs/ month)	54.4	10.5	2.0	9.3	37.3	194.7	248.4	556.6
Share in total household energy use (%)	20.8	4.2	0.6	3.9	7.4	37.5	25.6	100.0

** For many households, particularly in rural areas, expenditures on non-commercial fuels (wood, crop residue and others) are not reported, and were therefore imputed by regression models.*
*** Indian Rupee.* Source: Khandker et al. (2010).

Therefore, particularly in rural areas of developing countries, access to modern forms of energy such as electricity and oil is essential to improve the quality of life of villagers. The use of renewable energy and new technologies is expected to contribute to poverty alleviation by improvement of health conditions. This would be through replacing traditional stoves that emit large amounts of air pollutants, better education by providing electricity to schools, and creating new businesses and job opportunities. Reduced use of wood fuel will also decrease overcutting, which is a cause of desertification in drylands. Cost may be a problem, but rapid innovations and reduced costs of renewable energy technologies have expanded the potential of rural development projects.

I have investigated such projects linked to renewable energy and, based on surveys, I classify them into the following six types:

Type A: Renewable energy for domestic use (non-electricity)

Type B: Efficient use of traditional (biomass) energy

Type C: Generation of electricity from renewable sources

Type D: Renewable energy used for desalination of brackish water

Type E: Export of renewable energy outside

Type F: Production and use of biofuel

3.2 Examples of rural development projects linked to renewable energy

In type A, renewable energy sources such as wind, solar, plant biomass, and livestock manure have been used in villages. For example, there is a Clean Development Mechanism (CDM) project in Hubei, China (Hubei Eco-Farming Biogas Project Phase I 2008). This project introduces biogas digesters using pig manure. The produced biogas is used in the household for kitchen cooking.

In Type B, energy-saving appliances such as solar cookers, solar water heaters, and high-efficiency furnaces and stoves are introduced. For example, so-called stove projects have been carried out in many countries, like China and Pakistan. For Sub-Saharan Africa, a paper entitled *Wood Based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches* reviews the ways that the resource is developed and how supply and demand issues can be managed, particularly regarding household energy use (AFREA 2011).

In Type C, electricity generated by wind, solar, micro-hydro, and biomass power plants is used for lighting, heating, cooking, and other purposes. Table 5 shows that rural hospitals in Uganda, even large ones, lack access to the electric grid; small hospitals have no access to electricity (AFREA 2011). This situation should be improved. The Project for Renewable Energy in Rural Markets (PERMER) in Argentina is supported by the World Bank and Global Environment Facility (GEF). This project uses mixed renewable energy technologies such as photovoltaics, wind and mini-hydro power. (http://www.worldbank.org/projects/P110498/ar-permer-renewable-energy-additional-financing?lang=en)

With Type D, renewable energy is used for desalination of brackish water. In some areas with serious water shortages, seawater or brackish water is desalinated with electricity generated by renewable energy sources; the desalinated water is then used for drinking, agricultural irrigation, and other purposes. Table 6 summarizes the cost of desalinated seawater from renewable energy sources such as solar heat, photovoltaic and wind power (World Bank 2012). There is a wide range of cost according to the energy source and method. Therefore, it should be carefully examined if the cost would be reasonable relative to the benefit of the water used. On small islands, the supply of fresh water is critical. The Canary Islands Technological Institute has been developing renewable energy sources and desalinizing seawater, using the energy produced.

Table 5: Electricity access of Ugandan health facilities

	Access status (%)			
Facility type	**% of total**	**Grid or permanent mini-grid**	**Stand-alone diesel or solar system**	**No access**
Urban hospital	2	100 (except for a few district hospitals)	A few district hospitals	
Rural hospital (HC IV)	7	27–43 (NGO ones have higher access rates)	57–73	
Rural health center (HC III)	27	14	52	34
Rural dispensary (HC II)	65	6	29	65

Source: AFREA (2010)

Using the desalinized water for irrigation, they cultivate tomato, cucumber, green pepper and papaya (http://www.islenet.net/?secid=15&spid=57).

Table 6: Costs of desalinated seawater from renewable energy (RE) alternatives

RE source	**Solar heat**			**Photovoltaic**		**Wind**		
Desalination technology	CSP-MED	MEH	Stills	EDR	RO	MVC	RO	
							Small	Large
Production (m^3/day)	>5,000	1–100	<0.1	<100	<100	<100	50	1,000
Cost (Euro/m^3)	1.8–2.2	2–5	1–15	8–9	9–12	4–6	5–7	1.5–4.0

Note: CSP-MED: Concentrating solar power-multiple effect distillation, MEH: Multiple effect humidification, Stills: Solar still, EDR: Electro-dialysis reversal, RO: Reverse osmosis, MVC: Mechanical vapor compression. Source: World Bank (2012)

Type E represents relatively large-scale projects in which renewable energy is exported from the village, sometimes to other countries. For example, there is a plan to build massive solar thermal power plants in the Sahara Desert.

With Type F, renewable energy is produced from biofuel. In humid areas, plants that require substantial water such as oil palm, sugar cane and corn are cultivated. However, in drylands, it is difficult for such plants to be grown, so other plants such as Jatropha, Pongamia and Neem are being cultivated. On a large scale, such as biofuel plantations, the biofuel is refined to produce biodiesel or bioethanol. On a small scale, the biofuel is directly burnt for cooking or lighting. Rural villagers are familiar with farming, so their skills may be used to introduce biofuel crops.

4. Discussion

Regarding the pros and cons of rural development involving renewable energy, benefits can be separated into direct and indirect. Direct benefits from energy use include heating, cooking, motive power for engines, motors, and electricity (for light, television, radio, telephone, refrigerator, washing machine, and others). These will help villagers improve their quality of life.

Indirect benefits of small scale include health improvement by reduced use of dirty fuels, advancement of education by introducing indoor lighting, prevention of crime by streetlights, and reduction of working hours for collecting fuel wood. Benefits at large scale include creation of job opportunities for energy sector improvement in the rural economy and reduced fossil energy consumption, which mitigates global climate change.

Benefits aside, there are concerns about problems, constraints and limitations. These include initial cost for equipment construction, impairment of rural scenery by construction of wind farms or solar panels, interference with agriculture by introducing biofuel crops or land-use change for energy production, collapse of the traditional society by abandonment of agriculture (small-scale family farming) for employment in energy sectors or biofuel plantations, and a widening income gap between rich and poor.

Mwakaje (2012) addressed the likely impact of biofuel plantations on rural development in Tanzania, via interviews with villagers. His findings show both high expectations and concerns. The respondents anticipated benefits from employment, income-generating opportunities, access to markets for crops, and improved social services. However, male respondents in particular were concerned with land grabbing, and women with food security, water-use conflict, and access to clean energy.

Chaurey *et al.* (2004) suggested a framework of a sequential distributed-generation (DG)-based approach. In the first stage, these schemes would involve small-scale renewable energy technologies, such as solar home systems and dispersed productive activities. In the second stage, other renewable energy technologies such as biomass gasifiers, wind-diesel hybrid generators, and more advanced DG technologies such as microturbines, could also be deployed at the village level. Integration of various off-grid schemes into the main grid network would represent a subsequent stage. Therefore, such a development path should be considered for rural development projects related to renewable energy.

There are special issues involved for drylands. These lands have strong potential for solar/wind power generation because of ample sunshine and vacant land. Reduced wood fuel use may help prevent desertification or land degradation. Renewable energy can be used for water supplies for drinking and irrigation, by pumping well water or desalination of brackish water. Therefore, we should turn our attention to the potential of rural development projects related to renewable energy, which bring the aforementioned direct and indirect benefits.

5. Conclusions

There are several types of rural development projects related to renewable energy, and they have a wide range of potentials. The World Bank, UN Development Programme and other donors are supporting rural development projects linked to renewable energy. Consequently, such opportunities should be seized for dryland development.

Particularly in drylands with abundant sunshine and vacant land, renewable energy-based rural development is expected to contribute to prevention of desertification and the introduction of water supplies. If an appropriate mix of energy sources is implemented, the energy can be used for improving living conditions. In certain cases, the energy supplied can be used to produce desalinated water for irrigated agriculture.

Innovative thinking is required to integrate the exploitation of renewable energy sources and efficient and systematic energy use, toward achieving sustainable rural development. We must change the current paradigm: from a single target such as the introduction of an individual energy-saving technology or renewable energy production facility to comprehensive purposes for rural development; from subsidies to investment for promoting the rural economy and creation of job opportunities; and from introduction of a technology to construction of a new rural system, which enables dryland villages to seek synergies and avoid tradeoffs between renewable energy introduction and sustainable rural development, and between energy and desertification issues.

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Plenary Session 2

Increasing productivity and building resilience in agriculture systems: a critical investment for better livelihoods and food security in dry areas

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Abstract

Climate change has a serious impact on agriculture in dry areas for a variety of reasons. These include: reduced precipitation; more frequent droughts; increases in temperature; changes in climatic zones – from favourable to less favourable to agriculture; shorter growing seasons; and a threat from diseases and insect pests largely due to temperature increases that are emerging in areas where they were not previously a problem. Through these factors, climate change has a negative effect on all components of food security – including production and availability, accessibility, stability, and food supply. The strategies to be followed to cope with climate change in dry areas depend on the targeted production agro-ecosystem in these areas. Production systems in dry areas can be classified in two major agro-ecologies: 1) high potential, or more favourable areas; and 2) low potential areas or marginal lands. The strategies for coping with climate change in these two agro-ecologies differ significantly. For high potential areas, research clearly shows agriculture productivity can be increased through the sustainable intensification and diversification of food production systems. Strategies for enhancing food productivity under climate change include: adopting improved crop varieties that are adapted to biotic and abiotic stresses, and improved management of water and land resources with appropriate inputs. For low potential areas or marginal lands, the best strategy is to enhance the resilience of agricultural production systems to climate change. Pursuing production system intensification in these areas can cause serious and irreversible damage to these low potential agro-ecosystems, resulting in desertification. Here, an effective solution for countries is to develop integrated crop/rangeland/livestock production systems. In these low rainfall areas, small ruminants (mainly sheep and goats), provide an important source of livelihoods for the rural poor – as a stable source of nutrition and as income for farmers who can produce meat, and milk or wool products. Several examples from ICARDA's research program are presented that demonstrate how countries can successfully follow these strategies to improve food security in their high potential agro-ecologies of dry areas.

Introduction

Roughly 2.5 billion people – 30% of the world's population – inhabit the dry areas, which cover more than 40% of the world's land surface. Even as scarce natural resources, land degradation and frequent droughts severely challenge food production in the drylands, about one-third of the population in these areas depends on agriculture for their food security and livelihoods–a paradox that underpins the prevalence of poverty in these regions. Drylands are home to the poorest and most marginalized people in the world, with 16% of their population living in chronic poverty. A web of delicate ecosystem, climate change, demographics and global forces has specially aggravated the challenges faced by smallholder farmers – the major food producers in dry areas. With little financial or policy support in most low-income countries, these farmers live in a "poverty trap" while the environmental health continues to decline unchecked.

Dry areas, covering more than 40% of the world's land surface, are today under extreme stress as their naturally scarce water resources are depleting further at an alarming rate. The trend has been building up for decades from increasing populations, the expansion of agriculture with increased intensity of ground water abstraction, and diversion of ever more fresh water resources for farming uses. The per capita fresh water in dry area regions is now below 2000 m^3 while in some countries – most of them in Sub-Saharan Africa – the per capita share has crossed the water poverty line to below 1000 m^3.

While water scarcity is the key limiting factor in food production, the extent of land degradation seen in dry areas is creating almost desert-like conditions on both rain-fed and irrigated lands. Stemming largely from human activity, such as overgrazing, over-cultivation, deforestation and poorly planned irrigation system activities, desertification has become one of the biggest environmental as well as food security challenges facing the world today. Underground salinity and high surface salt from evaporation are further making soil unsustainable for crop production.

Yet another cause for the extreme vulnerability of farming in drylands is the recurrent droughts in these areas. Droughts are characteristic of low precipitation areas the world over and destroy the delicate balance of food production and livelihoods, often leading to migration of subsistence farmers and at times, even snowballing into a full-blown humanitarian crisis.

Hotter and drier drylands with climate change

Climate change is a serious threat to the environment and natural resources globally; however, its impacts are estimated to take a disproportionately large toll in the dry areas. There is much evidence based on the greenhouse gas emissions data to predict rise in mean temperatures and decline in the overall rainfall levels, particularly across the dry belts – a situation that will make agriculture in dry areas even more challenging and uncertain (Figures 1 and 2).

In many places, climate change is causing more frequent and intense periods of drought, resulting in a trend of drier soils. With already fragile ecosystems, the unreliable precipitation pattern from climate change has increased the vulnerability of farmers in dry areas to crop failures and falls in crop and livestock productivity. While temperatures have become more extreme – both hot and cold – the rise in mean temperatures is expected to shift the climatic zones in some regions. This will result in shorter growing seasons for farmers and in prevalence of pests and diseases in areas where they were not previously a threat to crops. As forecast by some climate change models, if the temperatures rises by 4 degrees Celsius, vast areas of dry lands will have their growing seasons cut by more than 20%. It is expected that some of the world's marginal lands will go out of production altogether as a result. For example, Syria and Jordan are predicted to lose 30% land from steppe to desert climate.

The socioeconomic plight

The sharp demographic trends over the past few years in dry areas are further compounding the challenges. Factors like rapidly increasing population with heavy youth distribution, high urbanization, and the highest unemployment rates in the world are putting an ever more increasing stress on the social, environmental and economic infrastructure.

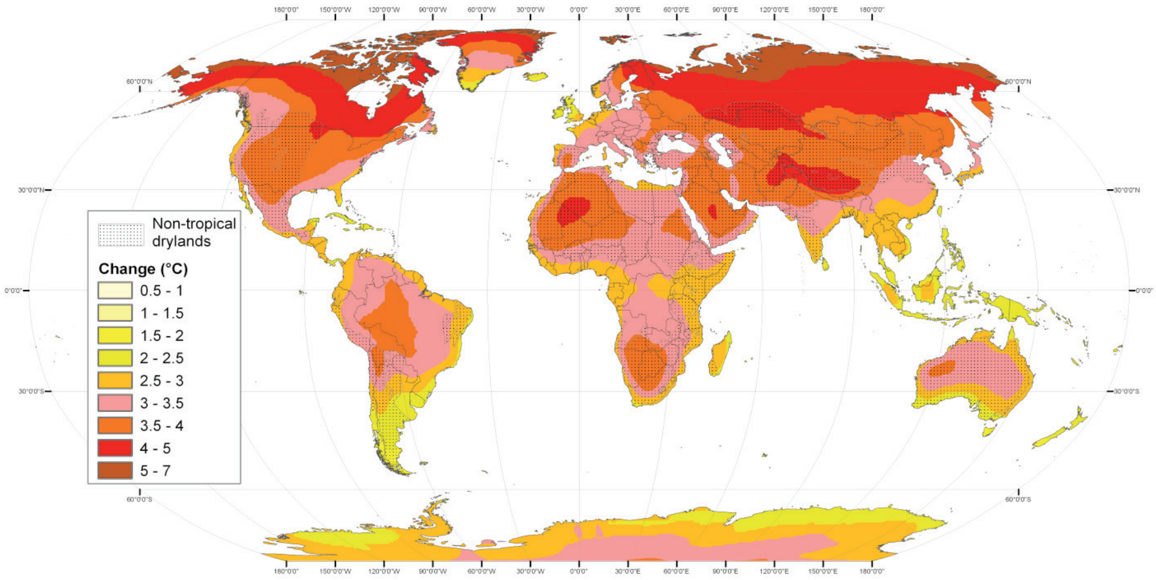

Figure 1: Estimated absolute change of mean annual temperature from 1980/1999 to 2080/2099.

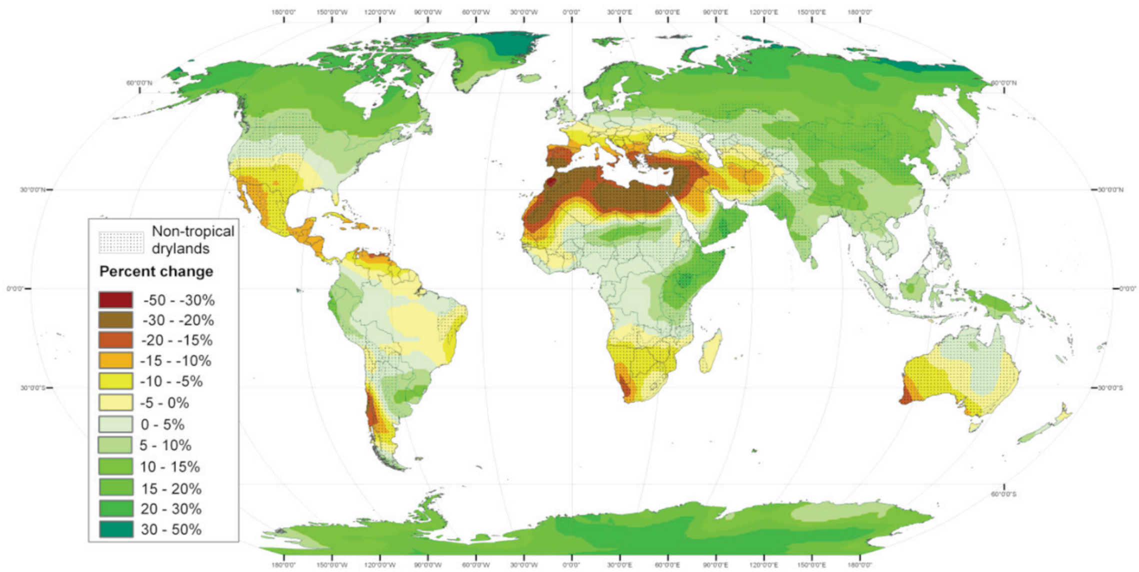

Figure 2: Estimated relative change of mean annual precipitation from 1980/1999 to 2080/2099.

The role of policy and institutions is critical to changing the course and bringing about large-scale impacts in development. Currently, there is a deep and widespread void for policy enablers to incentivize sustainable agriculture and effective water management practices in arid, low-income countries. Another deterrent has been insufficient investment in agricultural research and development. Developing countries typically have weak national agriculture research institutions with a shortage in the number of qualified researchers; for example the budget allocated for research in Arab countries is less than 0.4 of the GDP while the level in developed countries exceeds 3%.

Living in a changing world

Ever since the 2008 global food crisis, high and volatile food prices have become the new norm. According to the UN's Food and Agriculture Organization, the world prices for wheat and maize rose 115% and 204% respectively, between 2005 and 2011. Several factors are contributing to continued instability in food prices such as expanding economies of heavily populated countries like India and China, changing patterns in food diets, rising fuel prices, droughts and floods in wheat growing countries, and the growing use of food crops for biofuel production.

The aftermath has hit the low-income countries the hardest where there are poor safety nets. Families are spending larger percentage of their incomes on grains leaving less for other food items like vegetables and dairy products, which is taking a toll on their nutrition. With an estimated 400 million people in the dry areas living on less than US $1 per day, poverty and hunger are on the rise.

As the Figure 3 shows, the biggest losers from the food crisis were the dry areas since they are the largest importers of major food crops, particularly wheat. The predicted growing dependence of developing countries on cereal imports (Fig. 4) is bound to make them increasingly vulnerable to fluctuations in world food prices and their attendant causes such as extreme weather events from climate change, and economic and political instabilities the world over. Food security will continue to be the major challenge for the international community and action has become a dire need in today's world.

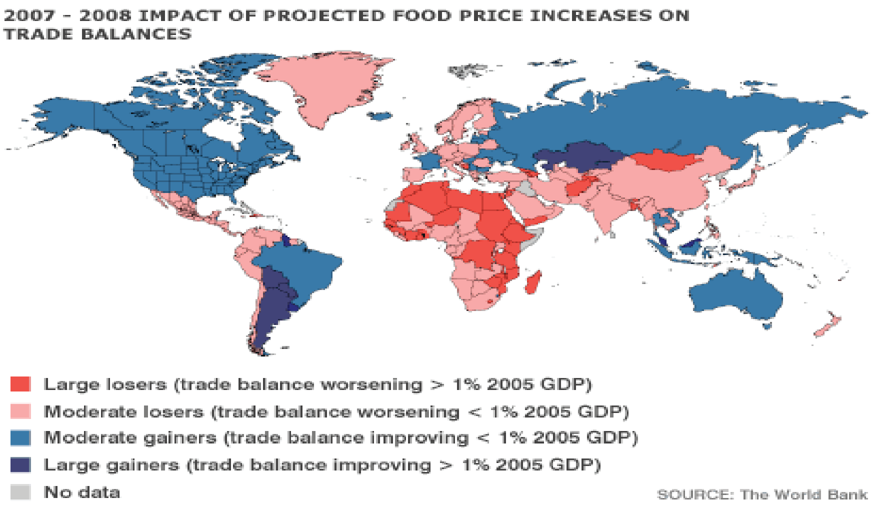

Figure 3: Impact of food price increases on trade balances 2007-2008.

Seizing the opportunity: bridging the yield gap

In spite of the harsh environment faced by people in the dry areas, their agro-ecosystems offer a number of advantages for agriculture, such as long days with good sunshine, a long growing season, and consistently warm temperatures. With strategic investments in research and technology transfer and efficient management of natural resources, dry areas can have tremendous potential to become highly productive and to strengthen food security.

Sustainable agricultural intensification offers a uniquely valuable solution to bridge the yield gap and enhance food security in all developing countries. However, the key word is “sustainable” – intensifying production is a serious threat to the environment and natural resources (biodiversity, water, land and soil) unless it is practiced in a sustainable manner particularly in dry areas where the ecosystem is already very fragile. This calls for yet another shift in the agriculture paradigm – a second phase in modernization after the Green Revolution which had unleashed a new era of food productivity and blossoming rural economies the world over, but had cost the environment dearly. The sharp increase in crop production from use of new technologies led to several negative impacts we see today such as land degradation, depletion of groundwater resources and salinization of irrigated areas.

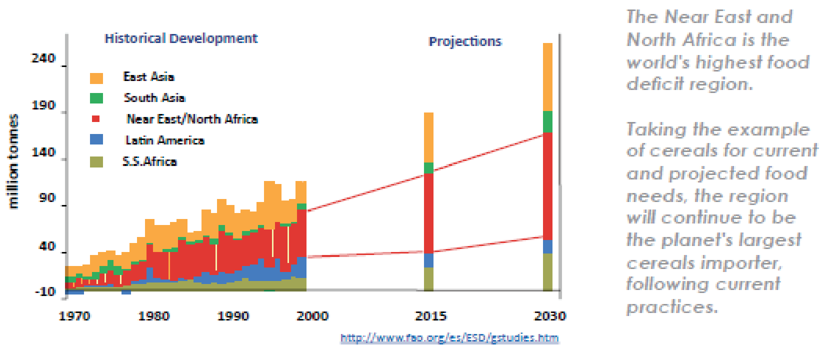

Figure 4: Cereal imports in different regions (1970 to 2030).

Sustainable agriculture offers a win-win solution for people and the planet and calls for improved management of drylands. It entails a more systemic approach to managing natural resources, and requires a holistic combination of science-based environmental, institutional and social solutions.

The CGIAR Research Program, ***Dryland Systems***, launched this year is grounded in these very principles – it addresses farming systems in dry areas globally with an innovative and holistic approach. As opposed to focusing on several aspects of farming individually, the *Dryland Systems* takes an integrated approach to study agro-ecosystems as a whole. Addressing crops, livestock, rangeland, trees, soils, water and policies, the approach intends to bring crosscutting impacts to improve people’s livelihoods in a more sustainable manner, while enabling long-term food security in the dryland countries.

Dryland Systems Program: the systemic approach for crosscutting impacts

Dryland Systems, led by ICARDA and involving 80 partners in 28 countries, is bringing ‘systems’ thinking to agriculture for the first time to improve livelihoods in the developing world. It uses modern innovation platforms to involve all stakeholders along the research-to-impact pathway. The global initiative has a sharp focus on specific outcomes and starts out with scoping out the needs and constraints in agricultural communities as the starting point and back tracks to shape a responsive research implementation agenda.

Built on the outcomes of ICARDA's on-farm, research-for-development work in more than 40 countries over the past 36 years, the program has identified a number of "best-bet" technology and policy packages that help countries reduce risk and improve national food security. These packages combine approaches such as: improved crop varieties; suggestions for diversification to new types of crops; effective land and water management practices; disease and pest management; socio-economic considerations; and the policy and institutional options necessary for these technologies to be adopted at country and regional level. These packages and expertise developed by ICARDA over the years are a starting point for the *Dryland Systems Program* and will be tested and validated for their effectiveness in specific agro-ecosystems so they can be scaled up in the dry areas across the globe.

A suite of science and technology interventions along with best practices will be implemented to increase agriculture productivity while building resilience in the systems – a critical criterion to withstand frequent droughts and impacts from climate change. The program is targeting five regions for large-scale impacts: (i) West Asia and North Africa, (ii) Western Africa and the Dry Savannas, (iii) Eastern and Southern Africa, (iv) Central Asia and (v) South Asia. Based on rigorous characterization of agro-ecosystems in these areas, the agriculture potential will be developed along two major paths:

- Low potential areas: In places with low rainfall areas including marginal lands, the target is to build resilience in the agriculture system to reduce vulnerability and risk and to enable smallholder farmers to recover from 'shocks' easily; and
- High potential areas: In places with relatively higher rainfall and/or water availability, the target is to develop options to sustainably intensify these production systems.

A suite of science and technology interventions along with best practices will be implemented to increase agriculture productivity while building resilience in the systems – a critical criterion to withstand frequent droughts and impacts from climate change. The details of the program have been presented elsewhere in this volume.

Examples of technical solutions for increasing yields and resilience in agriculture systems

1. Germplasm conservation and crop improvement

As the global population is expanding, particularly in dry areas, redefining the capabilities of crop plants remains the most cost-effective and powerful means of achieving food security. Robust ongoing research in dry areas on plant genetics and crop improvement has led to a rich repository of resources and tools that promise increased yields and resilience to climate change.

Over the past three decades, ICARDA research has led to the release and distribution of some 900+ seed varieties of cereals and legumes which have been adopted by smallholder farmers across the dryland countries with the help of respective National Agriculture Research Institutes. These varieties are providing higher yields; better tolerance to drought, heat, cold and salinity;

and improved resistance to diseases, weeds and insect pests. The total benefits are estimated at USD 850 million per year.

ICARDA scientists have genotyped several thousand barley, wheat and chickpea accessions, including wild relatives, within the production systems context using conventional and biotechnological plant breeding methods. A remarkable success story has been the almost four-fold increase in wheat yield in Syria since the 1970s, from about 1.2 million to 4.8 million tons today. Over 80 improved wheat varieties now cover about 90% of the total wheat area in the country. Syria was able to transform its status of wheat-importing to wheat-exporting country.

In Sudan, several high-yielding wheat cultivars with resistance to heat stress have been developed. This has made wheat an attractive crop in the South of Khartoum where heat stress once prevented its cultivation. Heat tolerance for wheat is a critical characteristic to help countries adapt their agriculture to climate change. In Jordan, Libya and Syria the drought-tolerant lentil varieties have been widely adopted by farmers due to their good economic returns even in dry years.

A recent scientific innovation**,** *the Focused Identification of Germplasm Strategy or FIGS,* has opened up yet another powerful approach to food security – a tool for rapid mining of genebank for useful traits. FIGS approach uses a combination of cutting edge mathematics and plant genetics to rapidly identify genetic traits suitable for local farming conditions.

2. Plant protection and integrated pest management

Integrated pest management (IPM) approach can prevent substantial yield losses every year from insects and pests infesting the crops. The IPM approach combines genetic resistance, environment friendly biocontrol methods, and cultural practices.

Stem leaf and yellow rusts are the most devastating wheat diseases. ICARDA's research involving mapping of the routes of the spread of these diseases in countries like Egypt, Ethiopia, Sudan and Yemen and identifying genes for resistance has led to continuously evolving effective strategies in handling the yellow rust disease. Since 2000, when the Ug99 rust disease was reported in South Africa, wheat has been threatened by this new race of stem rust which has the potential to devastate wheat crops globally and pose a real threat to food security. The Borlaug Global Rust Initiative, an initiative of ICARDA and CIMMYT (The International Maize and Wheat Improvement Center) launched in 2005, houses extensive expertise spanning 30 countries to develop and deploy wheat varieties with stable resistance to Ug99 and other races.

Major success has also been achieved in protecting wheat against the Sunn Pest insect, using IPM methods that include a major biocontrol component. The use of natural enemies decreases the amount of pesticide in the environment and reduces costs of inputs needed to protect the crop.

3. Better management of natural resources and higher water productivity

Sustainable increases of water productivity – at the farm and basin levels – are major concerns in dryalnd areas. Community participation is an integral part of the water management effort along with efficient use of resources and the use of technologies that increase water productivity.

ICARDA's large-scale research project on water management in 10 countries in West Asia and North Africa has shed light on the key drivers to increase water productivity at different scales:

- At basin level**:** competition among uses (environment, agriculture, domestic), conflicts between countries, and equity issues
- At the farm level: maximizing economic returns and nutrition in subsistence farming
- At the field level: maximizing biological output
- At national level: food security, availability of hard currency, and socio-political factors

Several technologies are available to improve the productivity of water depending on the agro-ecosystem – rainfed, irrigated and marginal lands:

- Modernization of irrigation systems and improving the efficiency of surface irrigation
- Modifying cropping patterns to enhance water productivity and income
- Supplemental irrigation (systems and management)
- Macro- and micro-water catchments
- Deficit irrigation to manage water in water scarce areas
- Watershed management

One way of maintaining yields under variable rainfalls in rainfed farming systems is to provide supplemental irrigation during periods of moisture stress. Research has shown that water use efficiency when applying supplemental irrigation is twice as high as in fully irrigated or rainfed schemes.

In areas where physical water availability is not a serious concern, it is important to determine the efficient management of water to ensure the sustainability of water resources and to reduce pressure on the environment. The raised bed farming technique has demonstrated efficient water management.

Policy is a critical enabler for water management and research has clearly demonstrated that under enabling policy environment, technology adoption is faster and reaches higher ceiling level.

4. Enhancing agricultural productivity and better livelihoods in marginal land

Crop-livestock integration is a crucial element in dryland farming systems as it allows toleverage available resources in a mutually beneficial manner. ICARDA has developed and refined a range of methods to effectively integrate crop-livestock-rangeland production systems. These include:

- Barley production with alley cropping of shrubs
- On-farm feed production
- Feed blocks produced from agro-industrial by-products
- Spineless cactus and fodder shrubs
- Natural pasture enhancement and rangeland management
- Increased animal productivity: animal health and nutrition, better use of genetic resources including wild breeds, improved flock management and better access to markets and value added by-products
- Improvement of rangelands: rehabilitate degraded rangelands, improve grazing management

Indigenous breeds of small ruminants are an important component of this integrated production system that is highly adaptable to changes in the environment. Years of livestock research at ICARDA has yielded complete characterization of all the indigenous ruminant breeds in Central and West Asia and North Africa and is freely available as an international resource.

Water productivity is also a key issue in crop-livestock systems. Technologies have been developed to enhance water productivity for feed production through feed selection, use of residues, feed water management and multiple uses of water. Traditional systems have been adapted to more sustainable practices, such as 'tabia' and 'jessour' systems of Tunisia have been adapted for water harvesting and watershed management. Other modifications can help reduce the pressure on rangelands, such as barley/livestock systems and considering rangeland/livestock versus confined feeding.

5. Conservation agriculture

Conservation agriculture offers a powerful approach to cope with climate change while bringing a suite of day-to-day benefits to the farmers in dry areas. It embodies an approach of minimum soil disturbance; stubble retention; and many rotations (legumes, oilseeds). With zero tillage, the farmers benefit from savings in time, fuel and machinery wear while soil retains more moisture and better soil structure. The less soil erosion provides for higher yield potential. Because of its many advantages, conservation agriculture has spread on more than 1000 million hectares mostly in Latin America and North America.

ICARDA's active promotion and creative partnerships with multiple stakeholders is helping to spread the practice in dry areas in Central Asia as well, where conservation agriculture now occupies roughly 1.2 million ha. In West Asia, it catapulted from near-zero to more than 28,000 hectares in Syria and Iraq, in less than 5 years.

However, for the low-income countries in West Asia and North Africa, the bottleneck has been the high cost of imported zero-tillage machinery needed. The benefits of conservation agriculture are now beginning to reach rural areas in Africa's dry areas as well through adaptation at the downstream end of the science- to- farms chain. ICARDA's scientists tapped into the local communities to develop seeding machinery at a fraction of the cost. The ingenious approach is now creating additional streams of revenue in the villages through machinery repair and maintenance jobs.

Conclusion

Food security is a paramount concern and challenge for the entire world today. In the dry areas, dealing with the food security is an even more acute and critical issue as many smallholder farmers are trapped in a perpetual cycle of poverty, poor crop yields, scarcity of natural resources, and a lack of supportive policies and institutions. The rapidly increasing population and a markedly higher vulnerability to climate change than other parts of the world will continue to aggravate the challenges faced by rural communities in dry areas. Investment in a systemic approach to agriculture in dryland areas is therefore critical as nations strategize for continued socio-economic development.

To meet the growing demands of the dry areas' expanding population, increasing the productivity of the agricultural systems in a sustainable manner is imperative. With its fragile ecosystem set to worsen from the impacts of climate change, sustainable management of natural resources must be the cornerstone of today's agricultural practices.

Today's suite of science and technology tools and resources offer the capability to unleash the potential of sustainable agricultural intensification in dry areas. With technology transfer, stronger food security and improved livelihoods are well within reach for dryland countries as success of pilot and large-scale projects in crop improvement, land and water management and crop-livestock systems has demonstrated.

The following key criteria can help scale up these technologies to deliver large-scale impacts:

- Prioritization of food security and water management and implementation of national strategies
- An enabling policy environment and regulatory framework
- Public awareness to promote acceptance and adoption of sustainable agricultural practices
- Capacity development and institutional support
- Partnership between all players – international and national institutions, governments, donors, NGOs, and the private sector as most of the challenges to improve livelihoods in dry areas are beyond the capacity of any one institution or country
- Increased investments in science and technology to address evolving and changing needs of the world and people

Human food: climate change mitigation and adaptation

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Extended abstract

Short and long term food security is a major international concern, likely to be exacerbated by climate change. Consequently improved adaptation and resilience of food production and supply are major priorities for developing and developed countries and international agencies. However greenhouse gas [GHG] emissions from the global food chain are major contributors to the anthropogenic emissions, although their impact is concealed by being allocated to several FAO sectors.

The 'agriculture sector', contributing a little over 12% to the total of ~45Gt CO_2e, collates emissions from enteric fermentation in ruminants, from manure and slurry, rice cultivation etc. CH_4 and N_2O emissions dominate. The 'land use, land use change and forestry' (LULUCF) sector, of similar magnitude, quantifies emissions (mainly CO_2) from land use conversion (e.g. decadal changes from grassland to crop-land, afforestation and deforestation, land brought into urban use) and from agronomic practices such as liming. Emissions from this sector are mostly consequential on food, animal fodder and, to an extent, bio-fuel demand. Together these sectors account for about 25% of global CO_2e emissions.

Other emissions arising from the food chain such as the production and distribution of NPK fertilizers, other agro-chemicals, off-farm transport, energy for glasshouse heating, commercial food transport, processing and preparation and domestic storage and cooking are distributed between other sectors and difficult to quantify accurately. Some factors, such as continued utilization and consequent oxidation of peat soils in long term agricultural and horticultural use, are not recorded. Industrial nitrogen fixation by the Haber-Bosch process alone accounts for 3-5% of natural gas use, releasing perhaps 0.3 Gt CO_2 (cf. 2010 CO_2 total of 35GT). The domestic emissions are significant, especially for certain food stuffs. These 'indirect' emissions raise the impact of the global human food chain to at least 30% of global emissions.

Some emissions would be curtailed if all energy supply and use e.g. for agricultural machinery, space heating, food processing and transport and N_2 fixation, were de-carbonised but a significant proportion would not. But agricultural N_2O and CH_4 alone contribute 10 to 15% of global emissions (~ 0.5 – 0.7t CO_2e *per capita*).This figure can be approximately doubled to 1 to 1.5 t if mainly CO_2 emissions from LULUCF are added: cf. total global emission of ~45Gt; i.e. *per capita* average of ~6t; current population ~7 billion (2011).

The future contribution to total GHG emissions arising from food production and use by 2050 has been calculated by extrapolating the proportions of different animal types and their diets and associated GHG emissions. We use trends observed since 1960, assuming that [a] global demand increases with human population growth (linear stock increase scenario (LSIS)) and [b] per capita meat consumption also increases, based on observed increases in global *per capita* consumption since 1960. This assumes, *de facto,* a steady growth in global 'middle class' prosperity (extrapolated increased stock scenario, EISS). In both scenarios it is assumed that [a] all non-animal emissions including the energy supply are decarbonised linearly by 85% by 2050; [b] global calamities are avoided, and [c] more resources are not diverted to energy crops.

Projections have been published of the trajectory of global emissions compatible with limiting the mean global temperature rise to 2°C; based on different climate sensitivity assumptions (from 1.5 to 4.5°C) and a critical total additive atmospheric CO_2e load. Estimates of this critical load for a 2°C temperature increase vary from 750 Gt CO_2 to 1000 Gt CO_2. Avoiding critical climate change requires an 85% decrease in global emissions. It is reasonable to suggest that to have any chance of re-equilibrating atmospheric radiation fluxes, all anthropogenic emissions must fall to between 1 and 1.5t CO_2e *per capita* by 2050 for the projected population of ~9-10 billion.

Assuming that GHG reductions in the global energy economy can be reflected fully in the food chain footprint, 85% of that element of total livestock emissions (both LSIS and EISS) would be eliminated by 2050. Nevertheless, despite holding the LULUCF contribution at its 2005 value - even though the cereal production required to support intensified livestock systems is likely to increase pressure on land - by 2050 livestock agriculture alone could account for >60% of the human GHG emissions budget in the '2°C model'. In LSIS, livestock agriculture would absorb more than our global per capita GHG budget before 2050. Including LULUCF emissions brings this intersection point forwards more than a decade.

We face a likely vicious cycle in which seeking to feed the world population in the face of climate change is the cause of further deterioration. Consequently mitigation cannot be excluded from the international agenda despite the pressure for adaption to future change and current challenges. Mitigation and adaptation must be seen as partners, lest we enter a vicious cycle of climate change brought about not only by fossil fuel burning but our sophisticated agricultural systems for feeding our growing population. Without such a partnership the search for resilience in the global food chain may be futile.

What can the arid agriculture movement learn from the success of urban agriculture?

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Extended abstract

One response to the desertification that climate change has engendered has been the rise of non-traditional agricultural clusters, such as urban agriculture. Urban agriculture has long been a fixture of the global agriculture market, where it is defined by Mougeot in1999 as "an industry located within (intra-urban) or on the fringe (peri-urban) of an urban center… which grows or raises, processes and distributes a diversity of food and non-food products, reusing and supplying [local products and services]". The Food and Agriculture Organization of the United Nations (FAO) estimates that 10% or more of Sub Saharan Africa's urban population, or around 11 million people, are active in urban agriculture, providing about a fifth of the world's food.

Despite this global impact, urban agriculture was rare in the United States, until a revolution began around a decade ago, whereby small enthusiastic agriculture groups began to collaborate to repurpose the abandoned lots and rooftops of U.S. cities into viable farms. Over time, the movement gained a political voice and began influence local zoning and permitting regulations. Technology has been crucial as well, with myriad growing methodologies being trialed including modified soil, hydroponic, aquaponic and aeroponic approaches. In the past 3-5 years, this grouping has been joined by investors keen to fund the expansion of such projects.

There are a number of lessons from the urban agriculture movement which could be applied to the arid agriculture one, especially as accelerating urbanization renders urban arid agriculture ever more important. That was the focus of this paper. Following a brief history of the urban agriculture movement, the work highlighted successful policies with regard to research, community engagement, and funding mechanisms that have been tried and tested during the urban agriculture movement and assessing their applicability to arid agriculture.

Plenary Session 3

Promoting sustainable use and management of water and energy resources under global climate change in dry areas

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Abstract

Sustainable development of dry areas is based on the sustainable use and management of water and energy resources where water resources are mainly ground water, while energy resources are basically solar and / or wind. To promote sustainable development of these dry areas, it is imperative to conserve the use of water and energy resources through their appropriate management. The global climate phenomena observed in some developed and developing dry areas is attributed to the increase in the burning of fossil fuels causing release of huge amounts of CO_2 in the atmosphere. On the other hand, the depletion of oil reserves as well as its increasing prices has prompted some countries to convert food grains into biofuels or ethanol which may restrict their exports of grain; thus causing a major problem for countries which do not enjoy food sufficiency. These changes in environmental and socio- economic conditions can be dealt with by ensuring the sustainable development of desert lands based on a holistic approach where agricultural, technological, socio- economic and environmental concepts are implemented.

One of the expected global warming effects in Egypt is the sinking of parts of the delta leading to the loss of agricultural, industrial, housing and domestic facilities. Those living, cultivating and having other activities on this land may have to migrate to new areas .With the overpopulated delta and Nile valley, sustainable desert development is the solution to the problem of settling the displaced population. For this to be achieved, it is necessary to save enough water from our present share from the Nile through increasing water use efficiency in the irrigation and cultivation systems of the delta and the valley by: **1)** decreasing water losses through water conveyance and distribution systems; **2)** changing the present flood irrigation system to more appropriate techniques leading to the use of lower quantities of water; and **3)** promoting regulations that would encourage farmers to use less amounts of water. For this to be achieved, it is proposed to create viable multipurpose communities based on a particular water basin serving reclaimed desert land, develop industrial and agro industrial as well as urban activities, which would cover the needs of those migrating from the sinking parts of the delta as well as others.

Introduction

The world in the 21st century is facing a number of challenges due to both environmental and economic factors. On the one hand, the tremendous increase in the burning of fossil fuel in developed and some developing countries has resulted in the release of huge amounts of CO_2 in the atmosphere, which has been considered a major cause of the global climate change phenomena. On the other hand, the depletion of oil reserves as well as its increasing prices has prompted some countries to convert food grains into biofuels, which may restrict their exports of grain to countries which do not enjoy food sufficiency. These changes in environmental and socio- economic conditions can be dealt with by ensuring the sustainable development of dry areas based on a holistic approach where agricultural, technological, socio- economic and environmental concepts are implemented.

Global climate change

Global climate change refers to any significant change in measures of climate (such as temperature, precipitation, wind) lasting for an extended period (decades or longer). Climate change may result from:

- natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun.
- natural processes within the climate system (e.g. changes in ocean circulation).
- human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.)

Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities. For over the past 200 years, the burning of fossil fuels, such as coal and oil, and deforestation have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our atmosphere. These gases prevent heat from escaping to space.

Greenhouse gases are necessary to life as we know it, because they keep the planet's surface warmer than it otherwise would be. But, as the concentrations of these gases continue to increase in the atmosphere, the Earth's temperature is climbing above past levels. According to NASA data, the Earth's average surface temperature has increased by about 0.74 ± 0.18 C^o in the last 100 years. The eight warmest years on record (since 1850) have all occurred since 1998, with the warmest year being 2005. Most of the warming in recent decades is very likely the result from human activities. Other aspects of the climate are also changing such as rainfall patterns, snow and ice cover, and sea level. If greenhouse gases continue to increase, climate models predict that the average temperature at the earth's surface could increase from 1.78 to 4.0 C^o above 1990 levels by the end of this century. Scientists are certain that human activities are changing the composition of the atmosphere, and that increasing the concentration of greenhouse gases will change the planet's climate.

Global climate change affects people, plants, and animals. Scientists are working to better understand future climate change and how the effects will vary by region and over time. Scientists have observed that some changes are already occurring. Observed effects include sea level rise, shrinking glaciers, changes in the range and distribution of plants and animals, trees blooming earlier, lengthening of growing seasons, ice on rivers and lakes freezing later and breaking up earlier, and thawing of permafrost. Another key issue being studied is how societies and the Earth's environment will adapt to or cope with climate change.

Reducing the amount of future climate change is called mitigation of climate change. The IPCC (Intergovernmental Panel on Climate Change) defines mitigation as activities that reduce greenhouse gas (GHG) emissions, or enhance the capacity of carbon sinks to absorb GHGs from the atmosphere. Many countries, both developing and developed, are aiming to use cleaner, less polluting, technologies. Use of these technologies aids mitigation and could result in substantial reductions in CO2 emissions. Policies include targets for emissions reductions, increased use of renewable energy, and increased energy efficiency. Studies indicate substantial potential for future reductions in emissions. Since even in the most optimistic scenario, fossil fuels are going to be used for years to come, mitigation may also involve carbon capture and storage, a process that traps CO2 produced by factories and gas or coal power stations and then stores it , usually underground.

Other policy responses include adaptation to climate change. Adaptation to climate change may be planned, e.g., by local or national government, or spontaneous, i.e., done privately without government intervention. The ability to adapt is closely linked to social and economic development. Even societies with high capacities to adapt are still vulnerable to climate change. Planned adaptation is already occurring on a limited basis. The barriers, limits, and costs of future adaptation are not fully understood.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

Global greenhouse GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.

Egypt is expected to suffer from Global warming through changes in the amount of Nile water, rising sea water levels (Fig.1), soil salinity and rising level of ground water near sea shores, as well as sand storms. The Mediterranean coast of Egypt, which borders the Egyptian delta, is expected to be strongly affected from global warming since this coast is originally below sea level and is harbouring a number of important cities such as Alexandria, Rosetta and Port Said. Based on earth and satellite measurements for the period 1994 to 2006, studies show that the average increase in global sea level is about 3mm per year. If we consider what is expected to happen in Alexandria alone under the case of rising sea water level by about 50 cm, a number touristic coasts as well as agricultural and industrial activities, and about 194000 employement opportunities (151000 industrial, 34000 touristic and 9000 agricultural) would be lost resulting in the need to migrate about 1.5 million people from Alexandria and its neighboring areas.

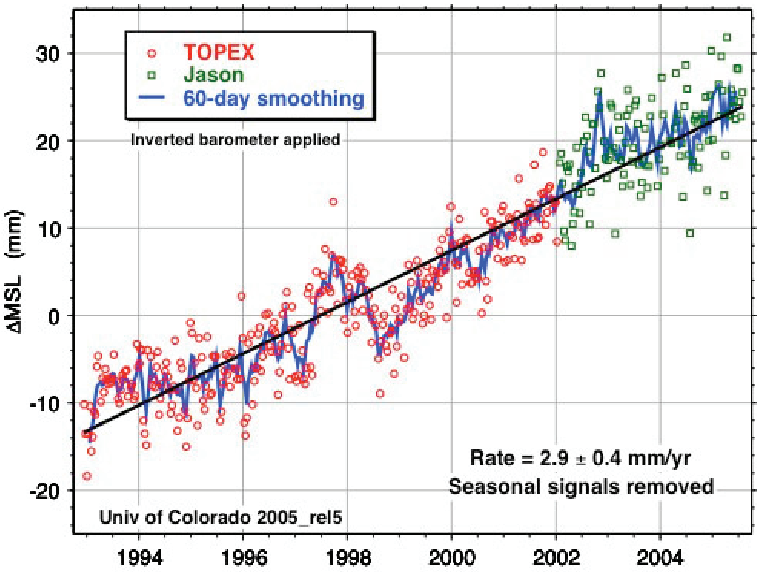

Figure 1: Average sea level elevation based on terrestrial and satellite measurements.

While some scientists and engineers propose diferent engineering means to protect our shores, I would like to consider an additional alternative, which would not only help to face this expected calamity but will also help to solve problems caused by our continous population expansion: move to the desert…. but do it properly!

Biofuels

Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels. The basic feedstocks for the production of first generation biofuels are often seeds or grains such as sunflower seeds (which are pressed to yield vegetable oil that can be used in biodiesel), or wheat/corn grains (which yields starch that is fermented into bioethanol). These feedstocks could instead enter the animal or human food chain. As the global population is increasing, the need for adding them to the food chain has risen and their use in producing biofuels has been criticised for diverting food away from the human food chain, leading to food shortages and price rises.

There is controversy and political speculation surrounding first-generation biofuels due to the agricultural, economic, and social implications associated with the potential expansion of biofuel production. Research done in China indicates that the demand for bio-fuel feedstock such as maize, sugarcane, and cassava will significantly increase due to the expansion of biofuel production; the increased demand for feedstock will lead prices for such grain to significantly increase. A similar study examining a potential increase in ethanol production capacity in the United States also predicts an upward trend in agricultural prices as a direct effect of expanding domestic biofuel production.

Expanding biofuel production is also projected to have an effect on livestock prices. A study done in China predicted that increased maize prices, due to biofuel expansion, will indirectly cause the prices of livestock production to increase due to the heavy reliance on maize for animal feed. Increased agricultural prices of corn and other sugar containing crops will also provide incentives for farmers to stray away from producing other less profitable grains, causing a shift in the crop production structure, leading to a decrease in agricultural diversity subsequently diverting food away from the human food chain. As an example, in order for the United States to meet the biofuel target introduced in the US Energy Independence and Security Act, 40% of the land that is currently devoted to corn production would have to be converted to biofuel feedstock production.

Shifts in crop production and the changes in world price of agricultural commodities due to the expansion of the biofuel market are expected to have global impacts on consumers. Individuals who are food insecure will be more heavily impacted by the increase in world prices; food price volatility has the largest impact on the extremely poor, those who spend 55-75% of their income on food. Accordingly, the tendency to convert corn and other plant material to biofuels by some countries due to depletion of natural oil reserves and its increasing prices, will result in decreasing export of grains thus causing a major problem for countries (such as Egypt) which currently do not enjoy wheat sufficiency. In order to overcome this situation , let us go to the desert… but do it properly.

Sustainable development of desert land

Egypt's water resources, based on current agreements with neighbouring countries, ranged from a total of 66.6 billion cubic meters in 2002/2003 to 73.06 billion cubic meters in 2008/2009. This includes Egypt's present share from the Nile, ground water from the valley and delta, treated agricultural waste water, treated municipal sewage, rain and floods, and sea water desalination (Table1).

Table 1: Water resources in Egypt (billion cubic meters per year)

Source	2002 /2003	2005/2006	2008/2009
Share from Nile water	55.5	55.5	55.5
Ground water	5.0	5.9	6.6
Treated agricultural waste	4.4	5.3	7.8
Treated municipal waste	0.7	1.1	1.8
Rain and floods	1.0	1.1	1.3
Sea water desalination	0	0.06	0.06
Total	66.6	68.96	73.06

These amounts cover agricultural (from 57.8 to 60.5 billion m^3/year), domestic, industrial and other uses. In addition, it should be stipulated that with increasing population the per capita annual amount of current and expected available water has decreased from 2604 m^3/year in 1947 to 860 m^3/year in 2003 and it is expected to come down further to 582m^3/year by 2025. We have been facing water scarcity (share of less than 1000m^3/year) since 1996.

The population in Egypt has increased from 9.7 million in 1897 to 80 million in 2009. Although, the area of cultivated land has gradually increased from 4.9 million feddans (1 fed= 0.4 ha) in 1897 to about 8.5 million fed in 2009, the per capita land availability has decreased from 0.5 fed to 0.1 fed per person. However, it should be emphasized that in addition to increasing population which by necessity would increase the need for additional water availability, two major factors should also be taken into consideration: (a) the expected effect of global climate change on the intensity of rain fall in the Nile valley, which would affect the share of Egypt from the Nile water; and (2) the current disagreement with the Nile water countries which claim that Egypt is currently taking more than its fair share (55.5 billion m^3). This state of affairs should warn us not to anticipate an increase in our present share from the Nile water, while making sure that we will be careful in utilizing every drop we get in the most efficient and useful application.

In addition to the above, one of the expected results of global warming is the sinking of part of the delta caused by the rising level of the Mediterranean. This state of affairs, if it happens, will result in the loss of homes for a large number of delta residents, as well as domestic, agricultural and industrial activities.

In order to deal with the above mentioned problem of decreasing water availability, and the need for additional habitable land (caused by increasing population and sinking parts of the delta land used for domestic, agricultural and industrial activities), the author proposes that the sustainable development of desert lands is the solution, provided that we save enough water from our present share from the Nile and other sources through increasing water use efficiency in the irrigation and cultivating systems of the delta and the valley by:1) decreasing water losses through water conveyance and distribution systems, 2) changing the present flood irrigation system to more appropriate techniques leading to the use of lower quantities of water, and 3) promoting regulations that would encourage farmers to use less amounts of water through proper choice of crops. This requires coordinated efforts in many disciplines related to the natural resources, technological aspects, and community aspects appropriate for the specific desert area .This integrated approach (Bishay1993) is the basis for different types of desert development systems (Fig. 2).

In 1979, the author had the honor of founding the American University of Cairo (AUC) Desert Development Center (DDC). In addition to adopting a systems approach integrating biological, technological and community aspects of desert development, we followed the following concepts: a) advocating that a desert should be treated as a desert (no outside manure or silt added to the soil), b) desert development should be based on a balance of appropriate indigenous methods with modern technologies, c) any trials for improving productivity should be environmentally compatible with

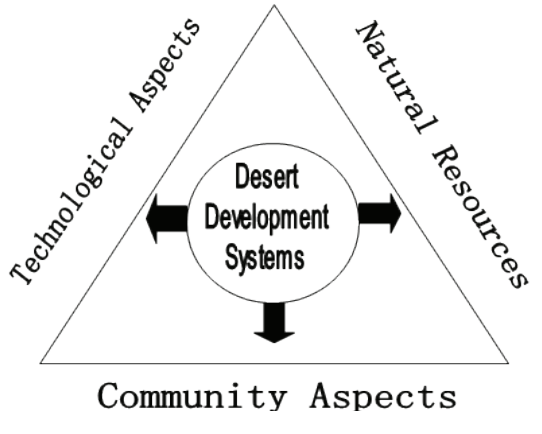

Figure 2: Desert development systems: An integrated approach.

desert conditions and economically replicable under prevailing social and technical constraints, d) the use of solar water heaters, photovoltaics, and passive solar architecture as well as wind energy and biogas should be promoted , and e) sprinkler and drip irrigation techniques should be used instead of flood irrigation, whenever possible, in order to ensure rationalization of use of good quality irrigation water and enhance its use efficiency. Now, more than thirty years later, the author is still a believer of this AUC/ DDC approach.

In 1990, a task force sponsored by the United Nations Development Programme (UNDP) and coordinated by the author, was assigned to propose strategies for sustainable development for Egypt (Bishay 1992). Sustainable development, or environmentally sound development, indicates that environment and development are closely linked and are mutually supportive. Sustainable development argues that “real” improvement cannot occur unless the strategies being formulated and implemented are ecologically sustainable over the long term, are consistent with social values and institutions, and encourage public participation in the development process. The primary objective is to provide lasting and secure livelihoods that minimize resource depletion, environmental degradation, cultural disruption, and socio-economic instability through a dynamic and adaptive process of trade-offs.

In order to achieve sustainable development (and self reliance), a balance should be reached between economic development, human development, resource management, and environmental protection (Bishay 2007). This is a dynamic system which would require appropriate management (especially under micro/ macro crisis conditions), necessary finances, and research and development with emphasis on optimization between ecological and economic dimensions of development. Public participation (social and political) and necessary infrastructure and supporting services are of utmost importance in implementing the different strategies proposed for achieving sustainable development. These strategies are grouped into four sets: (a) public policy and legislation; (b) information management, monitoring and public awareness; (c) technical support (training; research & development); and (d) institutional and international cooperation.

To achieve sustainable desert development we have to work with the limitations of water and energy scarcity, and population increase (Bishay 1996) . We also have to consider three additional main factors: 1) the possible effect of global warming on the loss of parts of the delta; 2) problems facing graduates (allocated 5-6 fed land each) and small farmers .These problems include marketing, inputs, appropriate technology, credit facilities, etc; 3) lack of coordination between different players in a certain region, including industry, agriculture and domestic activities, with emphasis on water management.

In order to solve the above mentioned problems, it is proposed to create viable multipurpose communities on a particular water basin basis. These communities would cover reclaimed agricultural desert land, industrial and agro- industrial as well as urban activities to cover the needs of those migrating from the sinking parts of the delta as well as young men and women who are looking for work or better working conditions. Thus, we would have rural, industrial and urban communities intermingled together in such a way that they would benefit from each other economically, socially and environmentally.

Proposed holding companies

To achieve the above mentioned objective, it is proposed to create holding companies, which would represent the delta migrants as well as unemployed graduates, small farm owners, business owners and other investors and players in the area. Each holding company and its specialized divisions must work towards supporting and developing the proposed multipurpose communities.

The mission of the Holding Company will be to help in solving the problems of the delta migrants, unemployed or small land holder graduates and small investors, to develop and support proposed multipurpose communities, and to work towards achieving sustainable development for the zone through promoting use of solar and wind sources as well as treated organic domestic and agricultural waste to produce needed energy. In addition, the company will ensure: 1) environmental protection against all types of pollution; 2) community development (providing necessary services and amenities, education, health, employment, etc.) with emphasis on public participation, financial, and technological activities; 3) proper planning and management of financial resources and providing credit services, purchasing inputs, marketing and/or processing of agricultural products; 4) initiating and supporting different area activities (agriculture, industry, agro- industry, renewable energy, tourism, mining and urban activities) ; and 5) research and development activities to ensure optimum management of resources, pollution control, integrated management of natural, human and historical resources.

The type and number of specialized companies belonging to the holding company will vary from one zone to another depending on location, availability of water, soil, raw materials and current as well as proposed activities. Also, specialized companies may be established gradually, giving priorities to those pertaining to the most needed activity. Each specialized company will be represented in the Board of Directors of the Holding Company. Also, delta migrants, small investors, and graduates will be represented in relevant specialized companies as well as in the holding company.

Structure of Holding Company

There will be a Board of Directors, with an elected Chairman who will be overall responsible for oversight and direction of the Company. There will be a Director General (DG) responsible to the Board to ensure coordination of the activities done through five divisions, and coordination between the Holding Company and different specialized companies. The five divisions (Business, Planning, Services, Evaluation & Follow up, and Research & Development) will each have a Head, to ensure activities as per the policy guidelines developed by the Board. The Head will be able to deal directly with specialized companies in matters concerning the division's field of activity. Each Division will have several departments to cover the range of the activities. As an example, the Business Division will have a Financial Department and a Personnel Department; the Planning Division a Technical Department and an Economic Department; and the Services Division will have departments dealing with infrastructure, water, energy, land , housing, education, health, etc.

Capital investment

Holding Company will have following distribution among share holders:

- 25 % Graduates and small investors in the zone.
- 35 % Government of Egypt (GOE) +Delta migrants.
- 25 % Specialized companies in the zone.
- 15 % Others (banks, insurance companies, etc).

Specialized Companies will have following distribution among share holders:

- 20 % Staff & labor)
- 29 % Open shares)
- 51% Holding Companies

Steps and time schedule for implementation of proposed plan

First the proposed scenario has to be presented to GOE and approval and/ or modification has to be secured. Then the selected desert zones will have to be identified, based on water resources sharing as well as the Ministry of Planning Sectoral Zones proposed earlier by the UNDP-sponsored project. Ministries to be involved will be Planning, Water Resources, Agriculture, Industry, Environment, Petroleum, Housing, Local Administration and Scientific Research. A feasibility study will have to be conducted for the above mentioned identified zone. Then necessary steps will have to be taken to form the Board of Directors of the Holding Company. Then the specialized companies to work in the identified zone and other share holders will be invited to participate.

Financing

The studies preceding formation of the Holding Company could be sponsored by one of the international agencies interested in environment and development or by the Ministry of International Cooperation. The paid capital of the Holding Company would be provided by different partners, based on the number of shares they would own. However, some mechanism must be formulated to enable delta migrants, graduates and small investors to pay for their shares. A loan from the Social Fund may be one possible alternative.

Conclusions

Egypt may have to face problems of decreasing water availability (caused by global warming and /or disagreements with Nile Valley countries), decreasing availability of fossil fuel, and finding additional habitable land for increasing population and the migrants from the sinking parts of the delta that might get submerged with rise of sea level. As a solution, it is proposed to create viable multipurpose communities based on a particular water basin. These communities would be associated with reclaimed desert land for agriculture, industrial and agro- industrial as well as urban activities covering the needs of those migrating from the sinking parts of the delta as well as young men and women who are looking for work or better working conditions. To achieve the above, it is proposed to create holding companies, which would represent the delta migrants as well as unemployed graduates, small farm owners, small business owners and other investors and players in the area. Each holding company and its specialized divisions must work towards supporting and developing the proposed multipurpose communities based on promoting use of solar and wind energy and treated organic domestic and agricultural waste to produce needed energy as well as promoting appropriate technological systems for agricultural, industrial and domestic needs resulting in decreased GHG emissions. It is also imperative that the holding company would take necessary actions to save enough water from our present share from the Nile and other sources through increasing irrigation water use efficiency in agriculture in delta and the valley by:1) decreasing water losses from water conveyance and distribution systems, 2) changing the present flood irrigation system to more appropriate techniques (drip, sprinkler, etc), leading to the use of lower quantities of water, and 3) promoting regulations that would encourage farmers to use less water through proper choice of crops and delivery cost regulation. The Sinai desert is the ideal location for the above mentioned multipurpose communities which are to be operated by holding companies. This will help in solving the problems of migration of millions of Egyptians from the region of delta that is likely to be submerged by the rising level of the Mediterranean Sea because of global warming. This would also help to solve the problem of increasing demand for land for agricultural, industrial and residential activities because of rising population. Furthermore, populating this location is also critical for insulating Egypt from criminal and strategic infiltration.

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Sustainable dryland management: an ecological and economic imperative

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Abstract

Sustainable land use is a keystone of sustainable development (SD) of drylands the world over. SD is a concept that people know about but opinions differ as to what it means in concrete terms. The key question is: "What do we want to maintain, for what purpose and for whom"? Many possibilities exist. These are elaborated in this paper as is some examination of the relationship between SD and improved land use practices. Sustainability of land use systems should be a high priority in all dryland regions because agriculture (including animal husbandry) is the cornerstone of the economic health and well-being of all. The meaning of sustainability presents problems, its meaning "in theory" is commonly intuited but "in practice" it is seldom really explained or understood. Likewise, there are the on-going responses to periodic changes in population density, weather patterns, competing land uses, alternative economic uses, and natural condition of resource base for each rangeland site. Perhaps a more appropriate goal is to strive for "more adaptable and sustainable ways of living for the dryland societies". Maintaining the productive quality of land resources for continued future use is one of the most important challenges directly confronting the rural population in drylands but the problems also impact on the wider society (both rural and urban) of all these countries. The intent of this paper is to identify which players, policies and procedures can best contribute to a more sustainable way of living of the rural societies and ensure that land is used in way that will allow future generations to enjoy the benefit stream that can flow from land that is used in a sustainable way. This gives rise to the concept of *intergenerational equity* and necessarily includes considerations about land stewardship.

Introduction

One-half of the world's countries have portions or all of their land in dryland environments. These lands and their sub-humid margins represent one-third of the earth's surface and are the home to nearly 40 percent of the world's population (Squires 2002). There is nothing new in the quest by humankind for permanent ways of using the land entrusted to them. The intent of this paper is to identify which players, policies and procedures can best contribute to a more sustainable way of living of the rural societies and ensure that land is used in way that will allow future generations to enjoy the benefit stream that can flow from land that is used in a sustainable way. This gives rise to the concepts of intergenerational equity and land stewardship (elaborated below).

Arid and semi-arid lands fall at the far end of at least four continua, including those of productivity, rainfall, complexity/heterogeneity, and scientific attention (Stafford Smith 1996). Low productivity tends to lead to large management units encompassing considerable spatial heterogeneity. Globally, rainfall variability increases with decreasing latitude, decreasing annual rainfall, and in regions subject to the ENSO phenomenon cycles of decade long dry periods. Variable rainfall in arid and semi-arid lands leads to intermittent productivity and makes it difficult to separate the effects of management from the effects of temporal variability (Squires 2007).

It is in drylands (including those where rainfed agriculture is practiced) that environmental degradation is occurring at alarming rates, often leading to desertification, and threatening the livelihood of more than 1 billion people. Drylands are diverse in terms of their climate, soils, flora, fauna, land use, and people. No consistent characterization or practical definition of drylands can be made because of this diversity. One binding feature of all dryland environments, however, is their aridity.

The drylands of the world also suffer from the vicious cycle of low productivity, low levels of investment, and, as a result, poverty. Investments, apart from those made for irrigated agriculture activities, are relatively low. Low productivity, low levels of investment, and land degradation often leading to desertification are responsible for regional poverty and income disparities. The poverty and hunger that are prevalent in sub-Saharan Africa is a poignant example of this situation. Other critical problems include the inherent problem of water scarcity, tenure considerations, and ineffective developmental policies (Mortimer 1998).

Improving this situation requires that a variety of technical and institutional problems be solved. Among the solutions is increasing the level of investments in appropriate agriculture, alternative land use practices, and other appropriate income-generating interventions. Other solutions are designing strategies for risk management and implementing programs for more equitable land distribution and levels of income (*ialcworld.org/conference/Pres-pdf/Ffol1px1.pdf*).

Arid and semi-arid lands exhibit further characteristics that make their dynamics and vulnerability unique, including:

- **modality** (the existence of multiple distinct states),
- **hysteresis** (recovery from disturbance is not always reversible by simply inverting the disturbance event and the path back from a disturbance is often different to the path forward), and
- **divergence** (relatively small changes in initial conditions can result in dramatically different outcomes with time).

Environment, at this scale, is also more than a collection of individual phenomena. The emergent ecological properties of landscapes at the scale of human communities are spatial pattern and diversity. Relative heterogeneity of patterns is an important factor in vulnerability to degradation.

Neither the biophysical environment nor human communities are static. Sustainable land use is possible only when the relevant changes and processes within community institutions and environment are spatially and temporally synchronous. Uncoupling in these processes can lead to social and environmental crises or collapse. Determining relative rates of change is, therefore, particularly important as accelerating environmental changes, including desertification, place new pressures to which the human–environment system must adapt (Vogt *et al.* 2011).

Despite this complexity, the possible ways in which relative rates of human–environment systems can change are not infinite; there is significant predictive power to be gained from classifying and modeling scenarios at an appropriate level of abstraction. Such a model framework can provide guidance for policy beyond past simplistic recommendations focusing solely on one component of the system or another.

The goal of management in drylands at the community scale (see below) and of policies to support better management, therefore, is the facilitation of adaptive capacity of communities and the understanding of the rates and spatial distribution of environmental change. Forecasting of environmental change can provide communities with important information concerning the state and trajectory of their environment which may enhance their adaptive capacity.

Sustainability of land use systems should be a high priority in all dryland regions because agriculture (including animal husbandry) is the cornerstone of the economic health and well-being of all of them. The meaning of sustainability presents problems, its meaning 'in theory' is commonly intuited but 'in practice' it is seldom really explained or understood. Likewise, there are the on-going responses to periodic changes in population density, weather patterns, competing land uses, alternative economic uses, and natural condition of resource base for each rangeland site. Perhaps a more appropriate goal is to strive for 'more adaptable and sustainable ways of living for the dryland societies'.

Maintaining the productive quality of and its resources for continued future use is one of the most important challenges directly confronting the rural population in drylands but the problems also impact on the wider society (both rural and urban) of all these countries.

Not all dryland is created equal

Drylands vary in their productive capacity, but this is not news! Climatologists have classified land into several categories based on the ratio of precipitation to evaporation (Table 1) and there are economic implications (see below).

Table 1: Bioclimatic zones and classification criteria of relevance to dryland

Bioclimatic zones	Humidity criteria
Hyper arid region	<0.05
Arid zone	0.05 - 0.20
Semi-arid zone	0. 20 - 0.50
Dry Sub-humid Zone	0. 50 - 0.65

As long ago as 1776 Adam Smith, the English economist, developed the concept of 'economic rent' that was elaborated later by Ricardo in 1817 and still later (1826) by the German geographer von Thünen. Heathcote (1983) has adapted the economic rent model of von Thünen (Fig. 1 [A] and [B]) to show the relationship between land productivity (as reflected in the economic rent that it generates) land use and the influence of rainfall (both the amount and its variability).

Market-driven systems depended on access to transport to markets for either live animals or as frozen or chilled meat products, e.g. export of meat from Argentina, Australia or New Zealand to the UK or the Euro-zone. In the sequence of zones the grazing of ruminant livestock on rangelands would be the most remote and last zone of productive use. Beyond this, nomadic peoples might still practice subsistence herding. The success of such nomadic systems depended on the unfettered movement to "chase" forage and water and often depended on altitudinal migration to summer pastures in higher altitudes (Kreutzmann 2012; Jacobs and Schloeder 2012) or long distance (500-1000 km) migration that may involve crossing international borders (Squires and Sidahmed 1998).

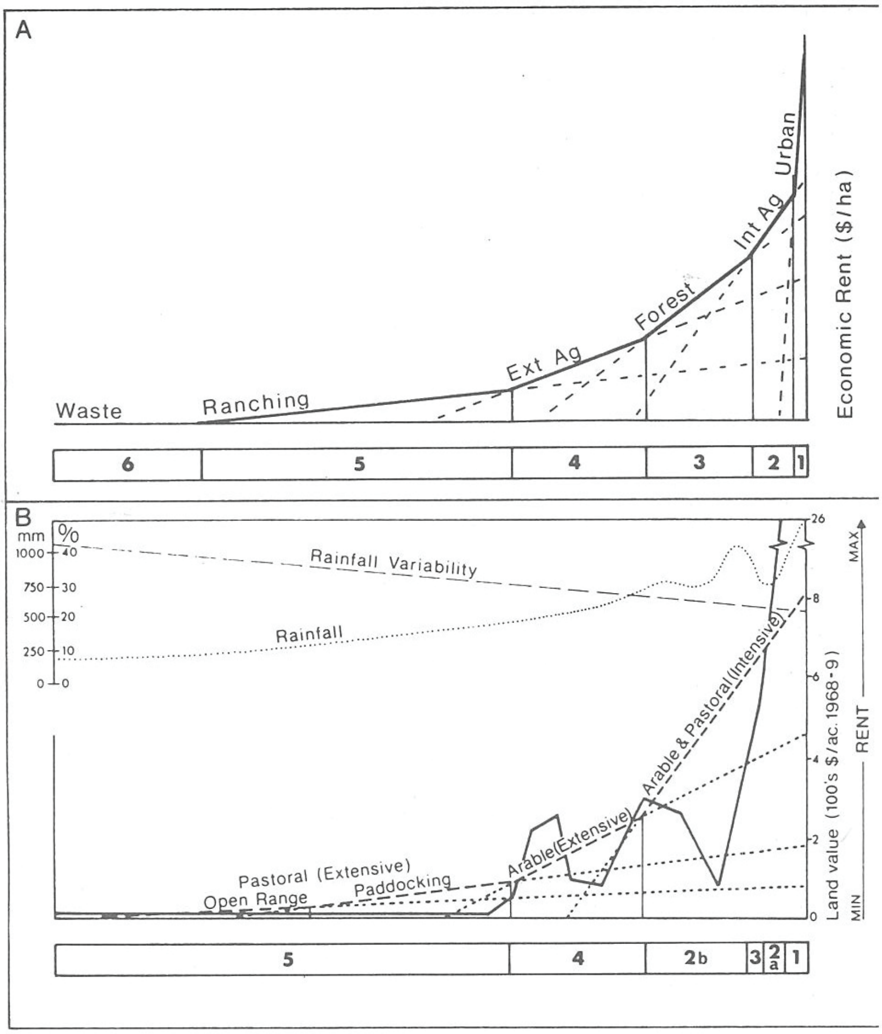

Figure 1: [A] A graph of economic rent as suggested by von Thünen (1826). Hypothetical land use was 1-Urban; 2 - Intensive agriculture; 3- Forest; 4- Extensive agriculture; 5-Ranching; 6-Wasteland. [B] Land use and land values ranging from intensive land use (far right) to pastoralism on unfenced 'open range'. Rainfall variability is greater as total precipitation decreases (after Heathcote 1983).

Climatic constraints might reduce the extent of potentially productive areas. As Figure 1[B] shows, the pastoral zone is at the arid end of any precipitation spectrum. An annual precipitation regime below 75 mm would probably preclude any pastoral use (nomadic or sedentary), although some camel-based systems might prevail on a subsistence basis.

Intergenerational equity

The first priority in all drylands is to maintain and restore the ecological sustainability of the watersheds and rangelands for present and future generations. To achieve and maintain the ecological sustainability of the rangelands while balancing the diverse economic and social needs of rangeland inhabitants along with conserving rangeland biodiversity and watershed values is a major challenge. The wider societies in dryland regions - both rural and urban - have an enormous stake in fostering progress toward profitable, environmentally friendly agricultural and pastoral systems; hence, the concerns about the need to foster land stewardship (Squires 2012). Regardless of how we define sustainable use of land it is ultimately the land user who must establish practical, sound practices. So the land users' point of view of what constitutes sustainable land management (SLM) is the most important perception of all. There is a clear need to bridge the gap between production and income objectives of the land users on the one hand, and the long-term objective of preserving natural resources on the other. The challenge that all dryland users face is how to achieve a balance between improved livelihoods, biodiversity conservation and land protection.

There are three intertwined strands of sustainable development that can also have negative impacts on land, often resulting in unwanted feedback loops. Poverty, food insecurity and vulnerability to climatic shocks are likely to remain the major global challenges for sustainable development in the next decades.

The maintenance of land and its resources for continued future use are the most important environmental problems directly confronting the rural population in the world's drylands. But the problems also impact on the wider society of all these countries. Even defining the problem and deciding which outcomes are best is fraught with difficulties, confusion and conflict. Enunciating the principles and practices which can make it work, particularly for rangeland-based industries and related rural populations is the first step. In its broadest sense, SLM is the recognition of the importance of retaining the quality and abundance of land, air, water and biodiversity, and to manage this natural capital in a way that conserves all of its values, be they environmental, economic, social or cultural. Although the definitions are almost limitless, there really are two clear and fundamental elements of SLM – awareness and action. That means recognizing the collective responsibility to retain the quality and abundance of our natural resources and putting that awareness into action by making the appropriate decisions for how to best use and manage these resources not only for today but for future generations as well. But implementation of decisions and monitoring outcomes are also required as the land user needs to periodically adapt improvements or changes to emerging conditions in response to past and on-going interventions/actions (Cowie *et al.* 2011).

The resource base for agriculture, including animal husbandry on arid and semi-arid rangelands, unless managed carefully and replenished continually, will dwindle in its capacity to produce at levels required to meet the demands of burgeoning population and changed market demands from an increasingly urbanized society. Production systems collapse or are forced to change when they become unprofitable to the land user or when they impose on households, neighbors or rural communities (or perhaps whole nations) excessive indirect costs or burdens. These indirect costs arise, for example, from increased frequency and severity of natural disasters such as floods or landslides that are attributable to poor land management.

Drylands are differentially vulnerable to degradation as a result of their scale as well as spatial and temporal heterogeneity in relation to their attendant land uses. The spatial scales of biophysical and social processes are not necessarily linked, although they may partially co-vary. A covariance of properties may exist in that a specific type of community will tend to occupy larger spatial areas and/or seek heterogeneity in some quality of the landscape or land area. For example, nomadic herders tend to require large and, preferably, heterogeneous areas to account for seasonal and other distributional qualities of grass and water. The specific spatial size of the range is associated with the level of vegetation productivity and seasonal differences in it, though not delimited by any single "natural" set of boundaries. Ecological diversity, at least compared to improved pasturage and farmlands dominated by 2–3 species, leads to complex interactions. The limited scientific attention that these lands have historically received, despite their relatively greater complexity, makes locally adapted management systems and knowledge vital for managers.

Local ecological knowledge (LEK)

Traditional methods of rainfed cropping and range management practices had been disregarded and undervalued for many decades as regional economic growth was seen as the key with application of modern technology as a means of increasing productivity and way to become modern. 'Modernity' is often associated with abundance, prosperity and a certain emancipation from the hard toil of working the land. Today however, we are witnessing a reversal of this trend and a return towards traditional methods that rely on local technical know-how and practices to restore degraded lands while halting desertification processes that threaten the livelihoods of local people; combating desertification is also a fight against poverty.

There is much valuable information to be learnt from the traditional lifestyles of the people in rural communities the world over, which have evolved over centuries and have thus carved and shaped both the natural and cultural landscape. This traditional knowledge may form the basis of site- and context-specific solutions in combating desertification in the world's dryland areas.

It would be misleading to suggest that all the solutions to the land degradation problems can be found by simply studying and adopting LEK and practices. There are possibilities of rediscovering traditional practice but clear and functional understandings diminish with time, and even when we have the chance to discover these fundamental approaches to sustain ability, by witnessing them at first hand or as a result of patient reconstruction, there still remains the arduous problem of reviving and making acceptable an enlightened approach in a world that is progressively losing its foundational roots in favour of a more dominant and wasteful economy.

It has been argued at several Conferences of the Parties of the UNCCD that 'traditional knowledge' has various advantages and benefits with regard to combating desertification: it is often considered a relatively inexpensive technology (compared with modern technology and computer-driven irrigation schemes, for example, or with drought-resistant genetically modified organisms), and therefore represents an affordable corpus of technology for developing countries and their populations (UNESCO 2005). As is well known, many dryland countries that are suffering from land degradation and desertification also rank among the poorest nations of the planet.

Most traditional land-use systems are associated with carefully adapted forms of social organization and regulatory frameworks for access to common resources and ecosystems management, combined with a deep knowledge of the dynamics of the ecosystem over a large territory that is made up of various ecological niches. Such often highly ingenious traditional management systems and cultures have co-evolved over centuries with the landscape and its components, including genetic resources. They are noteworthy for their contribution to biodiversity conservation, sustainable land, water and landscape management and to ensuring security of food, livelihood and quality of life. Many provide globally important goods and services well beyond their geographical limits. There is little doubt that LEK systems are a valuable resource for the management of drylands, as they are in other types of ecosystems. However, in many parts of the world, local or traditional management strategies are weakening or losing their relevance, due to rapid changes in their biophysical and socio-economic conditions.

Moreover, LEK has often been highlighted as a particularly 'environmentally-friendly' technology that also blends in with environmental conservation objectives in dryland ecosystems. But questions have been raised about whether the role of LEK has been oversold.

Is traditional knowledge indeed an effective means to combat desertification, or do we need to promote modern technologies in the interest of generating higher yields in the fields of agriculture, forestry and livestock husbandry? Is it possible to combine both traditional knowledge and modern technologies for effective and sustainable dryland management? These and other related questions on sustainable dryland management are being considered by various UN agencies, the donor community, NGOs and CSOs.

Pressures are constraining land user innovation and are leading to the adoption of unsustainable practices, over-exploitation of resources and declining productivity, as well as agricultural specialization and the adoption of exotic domesticated species. The result can be biodiversity loss, ecosystem degradation, poverty and loss of people's livelihoods (Squires *et al.* 2009). There is a risk of a severe erosion of the diverse base of agricultural and pastoral systems and their associated biodiversity, knowledge systems and cultures that ensure human livelihoods and healthy and resilient environments. These changes, some of which are driven by processes of globalization, outpace the evolutionary adaptive capacity of the local systems.

The focus over recent decades on agricultural productivity, specialization and global markets, and the associated disregard for externalities and adaptive management strategies, has led to a relative and general neglect of research and development support for diversified, ingenious systems. Whilst there is little doubt that LEK systems are a valuable resource for the management of drylands, in many parts of the world, local or traditional management strategies are weakening or losing their relevance, due to rapid changes in their biophysical and socio-economic situation.

Under these circumstances, and viewed from the perspective of the farmers and pastoralist communities, it is not particularly relevant to dwell upon the limits of applicability of LEK versus scientific knowledge. What is more interesting and urgent is how to develop approaches that successfully integrate the comparative strengths of both types of knowledge system. In this context there are three key questions:

- What are the different natures of LEK systems in drylands and of modern or scientific knowledge systems?
- What challenges, constraints and obstacles are there to strengthening traditional sustainable agricultural practices and their knowledge systems?

- What are the principles for an approach to safe-guard traditional management systems for the sustainable use of drylands?

Dryland communities: stakeholders, actors and decision makers

Dryland communities are not homogenous (Seely1998). Members of subgroups within a community commonly hold different priorities because of institutionalized differences in access to resources (e.g., livestock ownership, land tenure, user rights and inheritance).

Stakeholders, defined here as community subgroups with divergent interests, may perceive environmental change quite differently, have varying roles in driving that change, and respond to change in differing ways. The process of stakeholder division and negotiation, however, is a community process, one that commonly sits at the center of dryland degradation and remediation. Conflicts arising from differences can drive social change and may be a source of adaptive capacity and resilience, or they may lead to intractable conflict and so limit adaptation.

Communities are comprised of individuals, but individual actions aggregate to impacts and responses beyond the household level (e.g., cropping land similarly in a way that fosters soil erosion). Interactions among individuals and stakeholders generate emergent properties (wherein the whole is greater than the sum of its parts) within a human–environment system that may give rise to unique processes determining and influencing environmental conditions and change. These properties typically involve one or more of the following:

1. Institutions that control access to land, water, and other landed resources or the way in which these resources may be used (e.g., usufruct rights or the timing of grazing permitted on common land);
2. Means of accessing the state and higher authorities that influence access, production and welfare;
3. Mechanisms of access to subsidies, safety nets, and other means of combating the effects of land degradation;
4. Local environmental knowledge (LEK): codification of beliefs, knowledge, and ideologies that form the conceptual frameworks within which individual households view any changes in the environment.

The power of the community varies by circumstance. Among peoples only loosely integrated into the nation-state and the market economy, the community is commonly powerful, as it constitutes the traditional level of social organization that integrates individual decisions for the management of resources and resolves conflicts. Recognition of this role neither implies that traditional communities were or are necessarily effective in their management of resources, nor that modern ones are inherently ineffective. Traditional communities have, however, generally had a long period of time over which to adapt to environmental conditions; the relative rate of social and environmental change, therefore, becomes the central issue in determining the appropriateness of various forms of community management.

In arid lands, traditional communities are associated with extended kin groups and informal systems of decision making and sanction, like those of nomadic pastoralists, village agro-pastoralists, or rural farmer compounds. Sometimes formal institutions, including village development committees or advisory groups, have been imposed by a national government at the community scale. As these national institutions become influential, community-level influence often wanes. In developed market economies, communities are reflected in the voluntary clustering of land managers, such as pasture user or farmer associations, and the formal institutions of local government. Many communities, especially those in transition to a market economy, interact with community-level social structure and dynamics, and the influence of the nation-state grows or diminishes (Squires *et al.* 2009, 2010; Squires 2012).

The boundaries of human communities do not usually coincide with those of environmental systems, including catchments, soil types, or vegetation complexes. This can cause conflict, for example, where local government boundaries do not coincide with watersheds, incentives for coordinated management of invasive plants and erosion control are reduced. Communities do, however, often act to give rise to distinctive biotic landscapes and may create distinctive environmental conditions over their range as, for example, in parts of Western Africa, where communities have produced forest patches in and around savanna villages (Mortimer 1998).

The community, with its distinctive institutional and ecological position relative to the problem of dryland degradation, has a crucial and largely under-appreciated influence in combating desertification. Community-level processes serve to amplify or attenuate forces of degradation that emerge from differing scales, and community-level interventions have historically proven to both slow and accelerate environmental change. Community-level perceptions provide important alternative views, though ones that may differ among stakeholders. Stakeholders at the community level detect change, explain its causes, project trends, judge consequences, decide how to respond, and implement decisions (Kurbanova 2012).

Summary and conclusions

Sustainability involves the complex interactions of biological, physical and socio-economic factors and requires a comprehensive approach to dryland development in order to improve existing systems and develop new ones that are more sustainable (Squires 1998).

Several scenarios for sustainable land use have been articulated and most stress the following:

- The inter-connectedness of all parts of a dryland system, including the land users and their families
- The importance of the many biological balances in the system
- The need to maximize desired biological relationships in the system and to minimize use of materials or practices that disrupt these relationships

Recognition of the central role of human activities in processes of implementing SLM has taken a long time to become established (Seely 1998; Victor 1998; Reynolds & Stafford Smith 2002). Supporting research in socio-economic fields, in policy and governance, in economics, in communication and similar fields has gained increasing acceptance but remains far from sufficient (Squires 2012a).

Dryland environments must continue to be managed by dryland households (Mortimer 1998). Primary responsibility for making decisions about the management of natural resources in the drylands will continue to lie where it does now – with dryland households – and for three reasons. First, the intervention capabilities of many governments in the dryland areas, increasingly debt-strapped, under- resourced and dependent on external aid, are declining. Second, development objectives for the rural sector have shifted dramatically from overt transformation into new, more 'efficient' systems, to providing enabling structures and services, allowing farmers and livestock producers greater autonomy. Third, confidence in the applicability of scientific prescriptions to dryland management has been badly dented by many project failures, and, mean while, there has been a growing recognition of LEK (though its adaptive capacity, especially when enhanced by education, is probably still under-estimated).

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Producing more food with less water in the dry areas: Challenges and opportunities

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Abstract

The dry areas are experiencing severe and growing water scarcity. Its impact on food security and the environment, could potentially lead to socio-political instability and conflicts. Agriculture, the largest consumer of water, receives a progressively smaller proportion of total water resources – while food demand continues to rise. It is therefore essential for countries in the dry areas to produce more food with less water. Conventional approaches aim to increase crop yields (increase land productivity) while investing in modern irrigation systems – but this approach has major limitations. Higher crop yields generally require more water, which is hardly available. Modernizing irrigation systems may not result in real and substantial water savings; they increase the field and farm irrigation efficiencies, but not necessarily the overall efficiency at basin or landscape levels. In water-scarce areas, where water is more limiting than land, the focus must shift from land productivity to water productivity, which is the return per unit of water used. Research has shown that it is possible to double water productivity in the dry areas; this is equivalent to doubling available water resources. Water productivity can be increased through improving crop water management and technologies such as deficit irrigation, supplemental irrigation and water harvesting. Simultaneously, countries may cultivate highly water productive crops while importing crops with lower water productivity. However, this will require changes in cropping patterns, irrigation approaches, crop improvement strategies, policies and institutions; and greater investment in research and capacity development.

Limited water Resources; higher demand for food

Water continues to be crucial in the dry areas; but is becoming increasingly scarce as populations grow and demand increases. In many countries securing water needs for domestic use – let alone for agriculture, industry and recharge – is a serious challenge (FAO 2011). Agriculture is the major consumer of water. About 80% of the total water resources in the dry areas are used to produce food. With fast growing populations and improvements in living standards, more water is diverted to other priority sectors such as domestic and industry, leaving less water for agriculture. Ironically, as water for agriculture is declining, more food is needed and food security is being increasingly threatened.

Despite its scarcity, water continues to be misused. New technologies allow farmers to extract water at rates far in excess of recharge, rapidly depleting centuries-old aquifers. The productivity of water in the dry areas is still low but varies depending on crop and country. Water scarcity and mismanagement will also accelerate environmental degradation, through soil erosion, soil and water salinization, and waterlogging. These are global problems, but they are especially severe in the dry areas (Pereira *et al*. 2002).

The vast majority of water resources in the dry areas, includes surface and ground water, which are already tapped and used for various needs. A few technical options (listed below) might provide additional water resources, but many constraints must be overcome.

Desalinization is a potential source for new water but still expensive. Seawater desalinization costs around US$ 1.00 per m^3. The lower costs sometimes reported are due to subsidized energy. As new technologies develop, costs may eventually become feasible for agricultural use, possibly using natural gas as a source of energy. However, the potential for major breakthroughs is limited by lack of research funding.

Marginal-quality water development and use offers some promise. Potential sources include natural brackish water, agricultural drainage water, and treated effluent. Brackish water can either be utilized directly in agriculture or desalinated at low cost for human and industrial use. Treated effluent is an important source of water for agriculture in areas of extreme scarcity. However, the health and environmental issues must first be resolved. Agricultural drainage is becoming an attractive option. In the last two decades, there has been considerable research on reuse of drainage water in agriculture and its impacts on the environment.

Rainwater harvesting is a real recovery of otherwise lost water (evaporation and salt sinks) and it provides opportunities for decentralized community-based management of water resources. In dry environments, hundreds of billions of cubic meters of rainwater are lost every year due to lack of proper management. This loss occurs mostly in marginal lands, which occupy a major part of the dry areas. ICARDA has demonstrated that over 50% of this water can be captured and utilized for agriculture if the right methods are used (Oweis *et al*. 2012). However, policies and socioeconomic aspects require special attention.

Water transfers between basins and between countries have been discussed over the last decades. Transfer options depend on economical, political, and environmental measures, which are yet to be examined. As water scarcity in the dry areas grows, the issues associated with cross-boundary water resources become more urgent. Internationally agreed laws and code of ethics need to be developed to ensure water rights and to open the way for innovative projects.

Coping strategies with water scarcity: inadequate

Over the last few decades, substantial resources have been spent to increase food production in water scarce areas. The main strategies used to cope with water scarcity are not anymore adequate or effective.

Increasing yields

The Green Revolution transformed food production through improved cultivars, which yielded more than twice the old ones, combined with better fertility and water management. Other examples also illustrate large yield increases through proper management of water and cropping systems. However, higher yields generally require more water consumption. While higher yields (production per unit area) reflect more efficient use of resources, the relationship between yield and transpiration is nearly a straight line. This means that by increasing yields we do not save water in the same proportion. Substantial increases in crop yields require larger water supplies, which may not be available. Thus, a yield-targeting strategy alone cannot solve the problem.

Improving irrigation efficiency

The term 'efficiency' generally refers to the ratio of output to input. It is widely used in irrigation systems design, evaluation, and management. Farm irrigation performance is based on three fundamental and interrelated efficiency terms: conveyance, application, distribution and storage efficiencies. The first two are most relevant:

i. Water Conveyance Efficiency (WCE) is the ratio of water diverted from the source to that delivered to the farm. It reflects water losses from the conveyance system mainly in seepage, evaporation and weeds consumptive use.
ii. Irrigation Application Efficiency (IAE) is the ratio of the water stored in the plant root zone to that applied to the field. It mainly reflects losses of water in deep percolation and in runoff.

Water 'losses' implied in the above efficiency terms are mostly on paper, not real losses. Seepage from irrigation canals and field deep percolation losses are largely recoverable from adjacent groundwater or springs. Runoff losses end up in fields downstream. Drainage water is also recycled and used several times before becoming too saline. Although most of these losses are recoverable, engineers strive to minimize them as reuse implies some costs to the user and probably other implications.

These efficiencies are essential for design, monitoring, and performance evaluation of irrigation systems, but we must remember some caveats. Increasing application and conveyance efficiencies saves water at the farm level but not necessarily at the scheme or basin level as "lost" water can be recycled and reused downstream. And higher irrigation efficiency implies better irrigation performance – but not necessarily higher agricultural production.

Modernizing irrigation systems

Many countries strive to convert from traditional surface irrigation to modern systems such as drip and sprinklers, which deliver higher water application efficiency. The lower efficiency of surface systems is due to higher deep percolation and runoff losses. As indicated above, these losses occur at the field level but may be partially or fully recovered at the scheme or basin levels by recycling drainage and runoff losses or by pumping deep percolation losses from groundwater aquifers. Of course these are important losses to the farmer and recovering this water has a cost – but these are not total losses at the larger scale. Reducing losses by increasing irrigation efficiency (modern systems) will not create additional water resources. Irrigation losses in Egypt for example are recycled through the drainage systems several times before becoming .too saline for agricultural use

Modern systems such as sprinkler and drip irrigation can be efficient only if they are managed properly. In many areas they are no more efficient than surface systems because of poor management. In fact, surface systems may be better under certain circumstances especially as farmers understand them well. Selection of the appropriate system depends on the physical and socioeconomic conditions at the site.

Modern systems increase productivity not by reducing system losses in deep percolation and runoff, but through better control, higher irrigation uniformity and frequency, better fertilization and other factors. The benefits, however, come at a cost: capital, energy and maintenance. Successful conversion requires developed industry, skilled engineers, technicians and farmers, and regular maintenance. Modern systems are most successful in areas where water is scarce and expensive, so that farmers can recover the system cost by reducing irrigation losses and increasing productivity. When water is cheap and abundant, farmers have little incentive to convert to modern systems. In fact improving surface irrigation systems through land leveling and better control may be more appropriate for most farmers in developing countries. The vast majority of irrigation systems worldwide are surface irrigation; this is unlikely to change in the near future. A wise strategy is to invest more in improving surface irrigation, while simultaneously encouraging the use of modern systems when conditions are favorable (Oweis 2012).

Managing demand

Although water is extremely scarce in the Middle East, it is generally supplied free or at low and highly subsidized cost (Cosgrove & Rijsberman 2000). Farmers have little incentive to restrict their use of water or to spend money on new technologies to improve the use of available water. International agencies, donors and research institutes are advocating pricing schemes for water, based on total operational costs. Although it is widely accepted that water pricing would improve efficiency and increase investment in water projects, the concept of pricing presents enormous practical, social and political challenges.

Traditionally, water is considered as God's gift, to be distributed free to everyone. There is additional pressure from farmers for subsidized inputs. There is also a fear that once water is established as a market commodity, prices will be determined by the market, leaving the poor unable to buy water even for household needs. Downstream riparian countries fear that upstream countries may use international waters as a market commodity in the negotiations on .water rights

One cannot ignore these very real concerns. Innovative solutions are therefore needed to put a real value on water for improving efficiency but at the same time abiding by cultural norms and ensuring that people have sufficient water for basic needs. Subsidies for poor farmers may be better provided in areas other than water, so that subsidies do not encourage inefficiency. Countries must strengthen the recent trend to recover the running costs (operation and maintenance) of irrigation supply systems.

Water pricing and other forms of demand management will reduce demand for water in agriculture but may not increase agricultural production. This will benefit other water use sectors but will not contribute to increased food security.

Water productivity; broader approach

Improving irrigation efficiency, although necessary for better irrigation systems performance, does not reflect many aspects of agricultural water use, especially the returns to water used. Water productivity (WP) is the return or the benefits derived from each cubic meter of water consumed. This return may be biophysical (grain, meat, milk, fish etc), socio-economic (employment, income), environmental (carbon sequestration, ecosystem services) or nutritional (protein, calories etc.) (Molden *et al.* 2010). It is important to distinguish between water depleted and water diverted or applied, because not all water diverted (or supplied) to irrigation is depleted. Recoverable losses (such as surface runoff, deep percolation etc.) can be reused within the same domain or at higher landscape scale. More specifically, depleted water includes: evaporation, transpiration, water quality deterioration, and water incorporated in the product or plant tissues. Water recycled in the farming system may not be totally lost as implied by evaluating irrigation efficiencies. Water quality is important as water with various qualities has different productivity. It is now well understood that water productivity is a scale or level-dependent issue requiring a multidisciplinary approach (Molden *et al.* 2010).

Drivers to improve WP vary with scale. At the field scale it is desirable to maximize the biophysical WP of a specific crop or product. At the farm level, the farmer would like to maximize the economic return from the whole farm, involving one or multiple crops or products. At the country level the drivers for improved WP are food security and exports. At the basin level, competition between sectors, equity issues and conflicts may drive WP issues. It is important to note that the WP concept provides a standardized way of comparing crops and production areas, and for determining what to grow and where. Determination of cropping patterns should take into consideration drivers at all scales and all types of WP relevant to the population.

Improving agricultural water productivity may be achieved through the following (Kijne et al. 2003):

1. Increasing the productivity per unit of water consumed

- *Improved crop varieties* that give higher yields per unit of water consumed, or the same yields with less water.
- *Alternative crops:* switching to crops with lower water demand, or to crops with higher economic or physical productivity per unit of water consumed.
- *Deficit, supplemental, or precision irrigation:* offer better water control, and increase the returns per unit of water consumed.
- *Improved water management:* better timing of irrigation to reduce stress at critical crop growth stages, leading to increased yields; or by increasing the reliability of water supplies so that farmers invest more in other inputs, leading to higher output per unit of water.
- *Optimizing non-water inputs:* in association with irrigation strategies that increase WP, agronomic practices such as land preparation and fertilization can increase the returns per unit of water.
- *Policy reform and public awareness:* water use and valuation policies should be geared towards controlling water use, reducing water demand, safe use and disposal of water, and encouraging collective water management by users.

2. Reducing non-beneficial water depletion

- *Reducing evaporation from water applied* to irrigated fields through specific irrigation technologies (e.g. drip irrigation) or agronomic practices such as mulching, or changing planting dates to match periods of low evaporative demand.
- *Reducing evaporation from fallow land*, decreasing the area of free water surfaces, decreasing non-beneficial vegetation, controlling weeds.

- *Reducing water flows to sinks*—by interventions that reduce recoverable deep percolation and surface runoff.
- *Minimizing salinization of return flows*—by minimizing flows through saline soils or through saline groundwater to reduce pollution caused by the movement of salts into recoverable irrigation return flows.
- *Shunting polluted water to sinks*—to avoid the need to dilute with freshwater, saline or otherwise polluted water should be shunted directly to sinks.
- *Reusing return flow* through gravity and pump diversions to increase irrigated area.

3. Reallocating water among uses

- *Reallocating water from lower- to higher-value uses*. Reallocation will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, reallocation of water can have serious legal, equity and other social considerations that must be addressed.
- *Tapping uncommitted outflows* to be used for productive purposes
- *Improving management of existing facilities* to obtain greater benefits from existing water supplies.
- *Policy, design, management and institutional interventions* can stimulate expansion of irrigated area, increased cropping intensity or increased yields within the service areas.
- *Reducing delivery requirements* by improved application efficiency, water pricing, and improved allocation and distribution practices.
- *Adding storage facilities infrastructures* to store and regulate the use of uncommitted outflows, which are available in most wet years. This will make more water available for release during drier periods.

Major water-productive practices

Research has shown that it is feasible to at least double the current productivity of water used in agriculture. The potential increase is greatest in rainfed agriculture – where, in addition, greater public investment is the most feasible (Rockström *et al.* 2010). Research has shown that a cubic meter of water can produce several times the current levels of agricultural output through the use of efficient water management techniques. The following section describes some practices that can substantially increase agricultural water productivity:

Deficit irrigation

Irrigation schedules should be modified to increase WP. In water-scarce areas, irrigating for less than maximum yield per unit land (deficit irrigation) could save substantial amounts of water. The saved water could be used to irrigate new lands and thus produce more food from the available water. Guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in dry areas. This must be done as a priority.

In deficit irrigation, crops are deliberately allowed to sustain some degree of water deficit and yield reduction in order to maximize the productivity per unit of water used. One important merit of deficit supplemental irrigation is the greater potential for benefiting from unexpected rainfall due to the higher availability of storage space in the crop root zone. Results on wheat, obtained from trials on farmers' fields in Syria showed significant improvement in SI water productivity at lower application rates than at full irrigation. Highest water productivity of applied water was obtained at rates between 1/3 and 2/3 of full SI requirements, in addition to rainfall (Pereira *et al.* 2002).

Rainwater harvesting

Steppe or rangeland areas, which cover the vast majority of the world's dry areas, are facing rapid environmental degradation and declining livelihoods for local populations. Precipitation in these areas is generally too low and poorly distributed for viable crop production. One potential solution is water harvesting, defined as *"the process of concentrating precipitation through runoff and storing it for beneficial use".* This brings the amount of water available to the target area closer to the crop water requirements, increasing WP and economic viability of crop production (Oweis *et al.* 2012).

A wealth of information on traditional indigenous water harvesting practices is available. Indigenous systems such as *jessour* and *meskat* in Tunisia, *tabia* in Libya, *cisterns* in north Egypt, *hafaer* in Jordan, Syria and Sudan and many other techniques are still in use. Water harvesting can provide water for crops, trees, domestic use, livestock etc. It also directly reduces soil erosion and land degradation. Unfortunately, the introduction of systems which have been extensively tested under similar conditions elsewhere, is usually not accepted by the target groups. Several other constraints hinder the wider development of water harvesting systems, including technology inadequacy, lack of community involvement, poor design and implementation, land tenure issues, inadequate institutional structures, and absence of long-term government policies.

Supplemental irrigation

Shortage of soil moisture in rainfed agriculture often occurs during the most sensitive growth stages (flowering and grain filling), affecting crop growth and yield. Supplemental irrigation can substantially increase yield and water productivity, using a limited amount of water applied during critical crop growth stages, and to alleviate moisture stress during dry spells. Unlike full irrigation, the timing and amount of supplemental irrigation cannot be determined in advance owing to rainfall randomness.

Average WP of rain in wheat cultivation in the dry areas of West Asia and North Africa (WANA) ranges from about 0.35 to 1.00 kg grain/m^3. However, water used in supplemental irrigation yields more than 2.5 kg grain/m^3, i.e. in the same environment; supplemental irrigation gives WP twice as high as full irrigation. Clearly, water resources are better allocated to supplemental irrigation when other physical and economic conditions are favorable. In highland areas, supplemental irrigation can be used to plant winter crops early, avoiding frost and improving yields. In the highlands of Turkey and Iran, for example, early sowing with 50 mm of supplemental irrigation almost doubled the yields of rainfed wheat and barley, and gave WP as high s 3-4 kg/m^3 (Ilbeyi *et al.* 2006).

Alternative cropping patterns

Current land use and cropping patterns must be changed if more food is to be produced from less water. New land use systems that respond to external as well as internal factors must be developed based on water availability. This should include greater use of water efficient crops and varieties, and more efficient crop combinations. In cases of extreme water scarcity it may become viable to import 'virtual water' in the form of products – but imports from developing countries could threaten their food security. Choice of alternative crops and farming systems should be based on careful analysis of biophysical factors as well as the returns from the water used, including income, social and environmental aspects. New cropping patterns, in particular, must be introduced only gradually, and will often require policy support to encourage adoption.

Precision irrigation

Improved technologies that are currently available can at least double the amount of food produced – with no increase in water consumption – if implemented correctly. Implementing precision irrigation, such as micro- and sprinkler irrigation systems, laser leveling and other techniques can substantially improve water application and distribution efficiency. It is true that water lost during conveyance and on-farm application is not an absolute loss from a basin perspective, but its quality may deteriorate and its recovery comes at a cost. To account for these losses, the size of the irrigation system will significantly increase and this again comes at a very high cost. Policies to implement and transfer these technologies are vital. There is a need to provide farmers with more profitable, more efficient water management practices to replace traditional methods; and where necessary, to provide incentives to bring about technological change.

Conclusion

In water-scarce areas, water, not land, is the most limiting resource to agricultural development. Accordingly, the strategy of maximizing agricultural production per unit of land (land productivity) may not be appropriate for water scarce areas. Instead, a strategy based on maximizing the production per unit of water is more relevant. Fortunately practices for increasing water productivity also improve land productivity to some extent. A tradeoff needs to be made to optimize the use of both water and land resources (Oweis and Hachum 2009). This will require substantial changes in the way we plan and implement agricultural development.

"Business as usual" is no longer an option for agricultural water management in the water-scarce Middle East. Unless strategic changes are made, the dry areas will face increasing water and food insecurity. New thinking should drive new strategies and approaches, backed by concrete action at the country and local levels. Regulatory and legislative reforms in the water sector are needed, rationalizing use and attracting more investment while protecting the most vulnerable sections of the population. Policy support and funding for research and building human and institutional capacity are essential, to stimulate technological innovation. Local policies often contribute to slow adoption of available technologies. Policy reforms can bring about a substantial change in the way we manage water resources.

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Process of aeolian desertification and its control in Northern China

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Abstract

Aeolian desertification in Northern China is land degradation characterized by wind erosion in arid, semiarid and sub-humid regions mainly resulting from the excessive human activities on natural resources. With the development of economy and society, aeolian desertification/land degradation has exerted increasingly profound influences on natural environment and social development. The aeolian desertification mostly occurs in the interlacing agro-pastoral region, pastoral region, semiarid rain-fed cropland and oasis with irrigated cropland in Northern China and the whole situation of aeolian desertification comes to depravation as only part of the desertified land has been controlled. China, as one of the countries facing with severe desertification problems, has made some progresses in understanding and combating the process of aeolian desertification through many years of research. The results of remote sensing data analyses show that the there were 37.59×10^4 km^2 of aeolian desertified lands in Northern China in 2010. The area of aeolian desertified land increased at the rate of 2256 km^2 y^{-1} from1975 to 1990 to 3441 km^2 y^{-1} from1990 to 2000. Since late 1990s, some national projects have been carried out, such as “Grain for Green” and “Eco-reconstruction”, which has achieved positive results and many aeolian desertified lands have been transformed to become farmland and rangeland. The remote sensing data analyses confirmed that the average annual rate of decreasing aeolian desertified land were 1635 km^2 y^{-1} from 2000 to 2005 and 1114 km^2 y^{-1} from 2005 to 2010. Based on existing experiences and research achievements, this paper briefly discusses the developmental processes, assessment and control mechanism of aeolian desertification in Northern China so as to provide some basic experiences for further studies and combating the aeolian desertification.

1. Introduction

Desertification/land degradation is a very serious environment and socio-economic problem facing the world today. According to the UNCCD, and the actual situation in China, desertification can be classified into several major types, namely aeolian desertification (wind erosion), soil-water erosion, salinization etc. One of the main manifestations of desertification in Northern China is aeolian desertification. Since 1950s scientists in China have conducted a series of researches on natural conditions, resources, sand movement, wind erosion and its control on farmlands and grasslands, and rational use of water and land resources in desert and desertified regions. The popularization of the results of all these researches and technical work had laid a solid basis for launching large-scale land desertification studies in Northern China (Zhu *et al.* 1980; Zhu and Liu 1989; Zhu and Wang 1993; Wang and Zhu 2001;Wang *et al.* 2011). Through remote sensing monitoring, field investigation and statistical analysis, we found that aeolian desertification in Northern China expanded at an annual rate of 1560 km^2 from 1950s to 1970s, and aeolian desertified land occupied an area of $33.4 \times 10^4 km^2$ (Zhu and Wang 1990).

According to more than 30 years of research in land degradation regions in Northern China, we defined the aeolian desertification as “land degradation characterized by wind erosion mainly resulting from the excessive human activities in arid, semiarid and part of sub-humid regions in Northern China". In this respect, the relation between human and nature and their interaction must be stressed, i.e. only the land degradation resulting from the interaction of adverse effects of human activities with the wind-dominated external agents is called aeolian desertification.

2. The changes in aeolian desertification in Northern China from 1975 to 2010

The aeolian desertification is a gradual process of land degradation, so satellite image is a useful tool for monitoring this process over long periods in large areas, particularly when combined with field investigation and verification. To determine the development of desertification in northern China, we used Landsat MSS images mainly acquired from 1975, Landsat TM images mainly acquired from 1990, 2005, and 2010, and Landsat ETM images mainly acquired from 2000 to derive the desertified land databases; the actual image choice and year depended on the availability of suitable Landsat image data (e.g., cloud-free images). By overlaying data from consecutive years, we obtained the changed processes of the aeolian desertification from 1975 to 1990, 1990 to 2000, 2000 to 2005, and 2005 to 2010.

We found that the aeolian adesertified land area increased from 33.4×104 km^2 to 35.53×104 km^2 by an average annual rate of 0.23×104 km^2 from 1975 to 1990, then reached to 38.97×104 km^2 in 2000 with the annual increase rate of 0.34×104 km^2 from 1990 to 2000. From 2000 to 2005, the area of aeolian desertified land decreased by about 0.82×104 km^2 (so the total areas reached to 38.15×104 km^2) with an average annual decrease rate of 0.16×104 km^2. From 2005 to 2010, the area continued to decrease at an average annual rate of 0.11×104 km^2 and reached to 37.59×104 km^2 (Table 1).

2.1. Aeolian desertification from 1975 to 1990

During these 15 years, the area of aeolian desertified land in Northern China increased to 36.89×104 km^2. This increase was mainly because of the new slightly desertified land, which accounted for 42.3% of the total increment, whereas moderately, severely, and extremely severely desertified lands accounted for 26.0%, 19.6%, and 12.1% of the total increment respectively. The aeolian desertified land also decreased by 0.31×104 km^2 in various places, mainly in the extremely severe category, which accounted for 53.5% of the total reduction, whereas the severely, slightly, and moderately desertified land accounted for 20.1, 13.6, and 12.8% of the total reduction respectively. The net increase of 3.38×104 km^2 of aeolian desertified land amounted to an average annual net increase of 0.23×104 km^2. This increase comprised 4.17×104 km^2 of aeolian desertified land with increased aeolian desertification intensity, and 0.84×104 km^2 of aeolian desertified land with decreased aeolian desertification intensity. In total, 7.86×104 km^2 of aeolian desertification land developed and 1.14×104 km^2 of aeolian desertified land recovered, giving a net increase of 6.72×104 km^2 in aeolian desertification. This amounted to an average annual rate of increase of 0.45×104 km^2.

Table 1: Changes in aeolian desertified land in Northern China from 1975 to 2010 (km2)

Decade:	1975s	1990s	1975-1990s		2000s	1990s-2000s		2005s	2000-2005s		2010s	2005-2010s		1975-2010s	
			Change	Annual change		Change	Annual change		Change	Annual change		Change	Annual change	Change	Annual change
Beijing	11.53	11.80	0.28	0.02	10.95	-0.85	-0.09	8.06	-2.89	-0.58	3.62	-4.44	-0.89	-7.91	-0.23
Tianjin	4.98	4.98	0.00	0.00	5.25	0.27	0.03	5.21	-0.05	-0.01	3.35	-1.85	-0.37	-1.63	-0.05
Hebei	1728.39	1978.98	250.59	16.71	2076.85	97.87	9.79	1991.32	-85.53	-17.11	1777.64	-213.68	-42.74	49.25	1.41
Shanxi	37.17	44.71	7.54	0.50	50.51	5.80	0.58	20.39	-30.12	-6.02	10.83	-9.56	-1.91	-26.34	-0.75
Inner Mongolia	201153.92	227235.14	26081.22	1738.75	256661.66	29426.52	2942.65	253048.93	-3612.73	-722.55	250949.11	-2099.83	-419.97	49795.19	1422.72
Liaoning	194.25	358.56	164.31	10.95	798.44	439.88	43.99	799.32	0.87	0.17	779.89	-19.43	-3.89	585.64	16.73
Jilin	6088.88	7537.97	1449.09	96.61	9117.06	1579.08	157.91	8898.53	-218.53	-43.71	8770.10	-128.42	-25.68	2681.22	76.61
Heilongjiang	3607.09	4929.67	1322.59	88.17	6575.62	1645.95	164.59	5012.01	-1563.61	-312.72	4659.18	-352.83	-70.57	1052.09	30.06
Shandong	572.21	517.40	-54.81	-3.65	417.75	-99.65	-9.97	223.38	-194.37	-38.87	65.41	-157.97	-31.59	-506.80	-14.48
Henan	301.63	70.34	-231.30	-15.42	65.70	-4.63	-0.46	59.39	-6.32	-1.26	12.15	-47.24	-9.45	-289.48	-8.27
Sichuan	278.33	378.09	99.76	6.65	534.56	156.47	15.65	360.10	-174.45	-34.89	264.39	-95.72	-19.14	-13.94	-0.40
Shaanxi	11741.02	11848.01	107.00	7.13	11943.06	95.05	9.50	11666.93	-276.13	-55.23	11259.89	-407.04	-81.41	-481.13	-13.75
Gansu	12050.80	12412.20	361.40	24.09	12058.52	-353.68	-35.37	11848.70	-209.82	-41.96	11679.44	-169.25	-33.85	-371.36	-10.61
Qinghai	31214.18	33020.95	1806.77	120.45	35458.26	2437.31	243.73	34805.62	-652.64	-130.53	33265.12	-1540.49	-308.10	2050.94	58.60
Ningxia	4683.84	4933.30	249.46	16.63	4855.89	-77.41	-7.74	4722.34	-133.55	-26.71	4602.64	-119.70	-23.94	-81.20	-2.32
Xinjiang	47762.22	49986.65	2224.43	148.30	49053.58	-933.07	-93.31	48037.04	-1016.53	-203.31	47832.72	-204.32	-40.86	70.51	2.01
Total	321430.44	355268.75	33838.32	2255.89	389683.67	34414.91	3441.49	381507.25	-8176.42	-1635.28	375935.48	-5571.77	-1114.35	54505.05	1557.29

2.2. Aeolian desertification from 1990 to 2000

During these 10 years, the area of aeolian desertified land in Northern China increased to 4.13×104 km^2. The newly desertified land was mainly slightly desertified, and accounted for 59.3% of the total increment, whereas moderately, extremely severely, and severely desertified land accounted for 20.6, 10.1, and 10.0% of the total increment respectively. During the same period, 0.69×104 km^2 of aeolian desertified land showed recovery. This decrease in the area of desertified land was mainly in the extremely severe category, which accounted for 48.9% of the total reduction, whereas the severely, moderately, and slightly desertified land accounted for 24.6, 15.5, and 11.0% of the total reduction respectively. The net increase in the area of aeolian desertified land was 3.44×104 km^2, with an average annual rate of increase of 0.34×104 km^2. The total of 3.97×104 km^2 of aeolian desertified land showed increased desertification intensity, whereas 2.05×104 km^2 of desertified land showed decreased desertification intensity, giving a net area of 1.93×104 km^2 in which aeolian desertification intensity increased. The combined result was that on 8.11×104 km^2 the desertification developed and on 2.74×104 km^2 the desertification decreased, with a net increase of 5.37×104 km^2 of aeolian desertification, at an average annual rate of increase of 0.54×104 km^2.

2.3. Aeolian desertification trends from 2000 to 2005

During these 5 years, the area of newly aeolian desertified land in Northern China increased 457.33 km^2. The newly desertified land was mainly extremely severely aeolian desertified, which accounted for 45.7% of the total increment, whereas severely, moderately, and slightly desertified land accounted for 20.0, 18.3, and 16.0% of the total increment respectively. There was a reduction of 0.86×104 km^2 in the area of aeolian desertified land. This decrease was mainly in the area of slightly aeolian desertified land, which accounted for 35.6% of the total reduction, whereas the moderately, extremely severely, and severely aeolian desertified land accounted for 24.7, 22.9, and 16.8% of the total reduction respectively. There was a net decrease of 0.82×104 km^2 in the area of aeolian desertified land, at an average annual rate of 0.16×104 km^2. The total of 0.38×104 km^2 of aeolian desertified land showed increased desertification intensity, and 4.60×104 km^2 of aeolian desertified land showed decreased desertification intensity, with a net area of 4.22×104 km^2 in which aeolian desertification intensity decreased. The combined result was 0.43×104 km^2 of aeolian desertification developed and 5.46×104 km^2 of aeolian desertification decreased, with a net change of 5.03×104 km^2 area where aeolian desertification decreased at an average annual rate of 1.01×104 km^2.

2.4. Desertification trends from 2005 to 2010

During this 5 year period, the area of aeolian desertified land in Northern China increased by 429.75 km^2. The newly desertified land was mostly in the severe category, which accounted for 55.6% of the total increment, whereas slightly, moderately, and extremely severely desertified land accounted for 6.0, 15.5, and 22.9% of the total increment, respectively. There was a 0.60×104 km^2 decrease in the area of desertified land. The decrease was mainly in the area of slightly desertified land, which accounted for 45.8% of the total reduction, whereas moderately, severely, and extremely severely desertified land accounted for 22.1, 17.0, and 15.1% of the total reduction, respectively. There was a net decrease of desertified land of 0.56×104 km^2, at an average annual rate of 0.11×104 km^2. A total of 0.76×104 km^2 of desertified land showed increased desertification intensity, and 3.98×104 km^2 of desertified land showed decreased desertification intensity, for a net area of 3.22×104 km^2 with decreased desertification intensity. The combined result was 0.85×104 km^2 where desertification developed and 4.58×104 km^2 where desertification decreased, with a net decrease of 3.78×104 km^2 in the area of desertification, at an average annual rate of 0.76×104 km^2.

3. Combating aeolian desertification in Northern China

Aeolian desertification and its great impact have drawn much attention from various stakeholders in China (Government, communities, researchers, NGOs and the private sector). Since mid 1980s, many measures have been taken to prevent and combat aeolian desertification in Northern China. Especially, the Standing Committee of the National People's Congress has promulgated the Law of Aeolian Desertification Prevention in 2001, which is an important landmark of Chinese people combating aeolian desertification. Since then, the government and local people in aeolian desertified lands have strived to reverse the degraded land, enhance land productivity, and promote environment and livelihood. By these efforts, the achievements have been outstanding (Fullen and Mitchell 1994; Xue *et al.* 2005; Zhou *et al.* 2012; Qi *et al.* 2012) and the area of aeolian desertified lands decreased to 0.381 million km^2 in 2005 and 0.376 million km^2 in 2010 (Wang *et al.* 2004). This achievement is attributed to the implementation of combating aeolian desertification measures. In this section, the aim and principles of combating aeolian desertification have been introduced.

3.1. Aim of combating aeolian desertification

The aim of combating aeolian desertification are to rehabilitate degraded ecosystems and build up stable man-made eco-economic systems, which can ensure the sustainable development of the ecological environment and natural resources and provide economic growth for society. The experiences on combating aeolian desertification in China proved that five basic principles must .be followed to achieve the aims

3.2. Principles of combating aeolian desertification

3.2.1. Prevention-oriented, control balance

First of all, a great amount of researches have shown that the recovery of degraded ecosystem is long term process. Under the artificial intervention such as prohibiting cropping and grazing, and planting trees, shrubs and grasses in degraded land, vegetation cover can increase significantly in a short time, but physical and chemical properties of the soil recover slowly. So, the recovery of severely degraded land is very long process, and needs much money and time. On the contrary, small investment in slightly degraded and non-degraded lands can effectively control the aeolian desertification expansion in the fragile ecosystem. Therefore, preventing the expansion of aeolian desertified land with small economic and technical inputs is more important than reversing the existing degraded land, especially, severely degraded land, requiring much funds and time.

3.2.2. Take actions that suit local circumstance

Our research shows that the patterns and causes of aeolian desertification in different regions are different. The local situation, the character and causes of aeolian desertification must be considered and analyzed before taking any measures. In China, biological, mechanical and chemical measures have always been used to combat and control the aeolian desertified land. Among the three measures, the mechanical measures are generally used in arid region with the yearly precipitation less than 200 mm, biological measure are used in sub humid region and semi arid region with the yearly precipitation of 200-400 mm, and the chemical measures are used in regions that need immediate action to prevent wind erosion. In addition, there are different methods, materials, and species for different regions. For example, the kind of materials preventing sand blowing depends on the local circumstances and priority. In some regions, wheat straw and cotton stalks are easily available to construct the straw checkerboard barriers, but in other regions where wheat straw and cotton stalks are not available, nylon, gravel and even sand bags can be selected to construct the checkerboard barriers. Similarly, the kind of vegetation (tree, shrub and grass) to be selected to increase the ground cover also depends on the local climate and water resources. That is to say, respect the nature and be in harmony with nature is the most important principle of combating aeolian desertification.

3.2.3. Policies, technologies and finance input from outside the degraded system

Aeolian desertified land is mainly distributed in the regions with fragile environment and poor economic situation. Therefore, relying only on the local resources from the society and ecosystem, the restoration of degraded land is impossible. Firstly, right policies and judicial and administrative proceedings from the national government are essential for implementing the process of combating regional aeolian desertification. Secondly, active and broad public participation is very important, which will be beneficial for the input of knowledge, information and funds from outside of the degraded ecosystem. Here, public participation includes private sector, indigenous peoples, non-governmental organizations, local authorities, workers and trade unions, business and industry, the scientific and technological community, and farmers, as well as other stakeholders, including local communities, volunteer groups. This would ensure steady and predictable access to adequate science and technology information, and financing for combating aeolian desertification.

3.2.4. Balancing long-term ecological benefits and short-term economic benefits

A host of facts from different regions and countries have proved that economic development cannot be at the cost of environment, because the sustainable development needs the good ecological environment. At the same time, combating aeolian desertification cannot neglect the livehood because the policies need the support from farmers. Therefore, a balance between the long-term ecological benefits and short-term economic benefits is essential. For example, fruit trees, shrubs and grasses with high economy benefits should be planted not only to increase the ground cover but also to increase farmers' income. When prevention of overgrazing is implemented, the artificial grasslands, livestock stables and some management measures must accompany to guarantee economic benefit to the herders.

3.2.5. Interregional eco-compensation for eco-services

Land degradation of an ecosystem does not entirely come from the factors inside the ecosystem. Sometimes the outer factors play more important role. For example, the people living in the upper reach of a river consuming too much water will cause the shortage of water and encourage aeolian desertification in the down reaches. Therefore, balancing the interest of various stakeholders involved in the process of aeolian desertification is also vital to combat aeolian desertification. Some measures for interregional eco-compensation should be considered, such as the upstream and midstream catchments should provide water use compensation to downstream catchment, industry should provide resource-use compensation to agriculture, and urban areas should provide compensation for eco-services to rural areas, and forest and wetland communities.

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Plenary Session 4

Sustainable dryland cropping systems to enable bioenergy security in the United States

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Abstract

The United States government, in an effort to reduce the nation's dependence on petroleum and advance energy security, mandates the production of 136 billion liters of biofuel by 2022. To meet this goal, a coordinated research program was initiated in 2010 by the United States Department of Agriculture (USDA). Regional Biomass Research Centers were established to address the barriers and capacities to produce biofuels across the highly diversified agricultural regions of the United States. In the western United States, where precipitation limits crop diversity and production, biofuel is anticipated to be produced from a limited number of agricultural feedstocks. The most promising feedstocks include crop residue and oilseeds. Removal of crop residue for biofuel may only be possible within certain areas of the western United States because retention of crop residue is vital to maintaining or improving soil quality across broader areas with low biomass production. A limited number of oilseed crops have been grown with success in localized areas in the west, but their absence from cropping systems is largely due to the lack of viable markets. Camelina appears promising as an oilseed crop, but adoption to the region will require development of high yielding cultivars and agronomic and rotational practices that are profitable and protect environmental resources. Partnerships among the USDA Agricultural Research Service (ARS), industry, and universities have been developed as an initial step toward developing and testing sustainable bioenergy cropping systems to achieve bioenergy security.

A strategy towards bioenergy security

The United States Government has advocated the development of renewable energy sources since the creation of the Department of Energy (DOE) in 1977. With 45% of petroleum consumed in the United States coming from other nations, the United States government has placed a greater emphasis on reducing the nation's dependence on foreign oil. The Biofuels Interagency Working Group (BIWG) was formed by the President of the United States in 2009 to decrease the nation's dependence on foreign oil by increasing the production of domestic fuels. The BIWG was composed of representatives from the Department of Agriculture (USDA), DOE and the Environmental Protection Agency (EPA). The BIWG released a report entitled *Growing America's Fuel* in 2010 that described a new approach to meeting the goals set forth by the Energy Independence and Security Act of 2007. This Act mandates the use of 136 billion liters of biofuel in the transportation industry by the year 2022. Of this, 57 billion liters must come from cornstarch feedstock while 79 billion liters must be produced from advanced biofuel derived using non-cornstarch feedstock such as sugar, cellulosic, or waste material. The United States is nearing the mandate to produce 57 billion liters of cornstarch ethanol, but only recently began to develop a strategy to produce 79 billion liters of advanced biofuels. As part of this effort, Secretary of Agriculture Thomas Vilsack announced the creation of five USDA Biomass Research Centers on 21 October 2010.

Biomass research centers

Five regional Biomass Research Centers were created by the USDA in 2010 to accelerate the production of feedstock for biofuel. The five research centers are comprised of a network of over 100 existing USDA-ARS and Forest Service (FS) locations (Fig. 1). The centers facilitate the coordination of existing and future research for enhancing the establishment of regional biofuel supply chains based on agricultural and forestry feedstocks. Research related to biomass supply chains is currently being conducted at many ARS and FS locations, consisting of dedicated feedstock development through 1) genetics and breeding, 2) agronomy, 3) feedstock conversion, 4) life cycle analysis, and 5) ecosystem services. The centers also provide long-term leadership in partnering with other federal and state agencies, universities, and private industry.

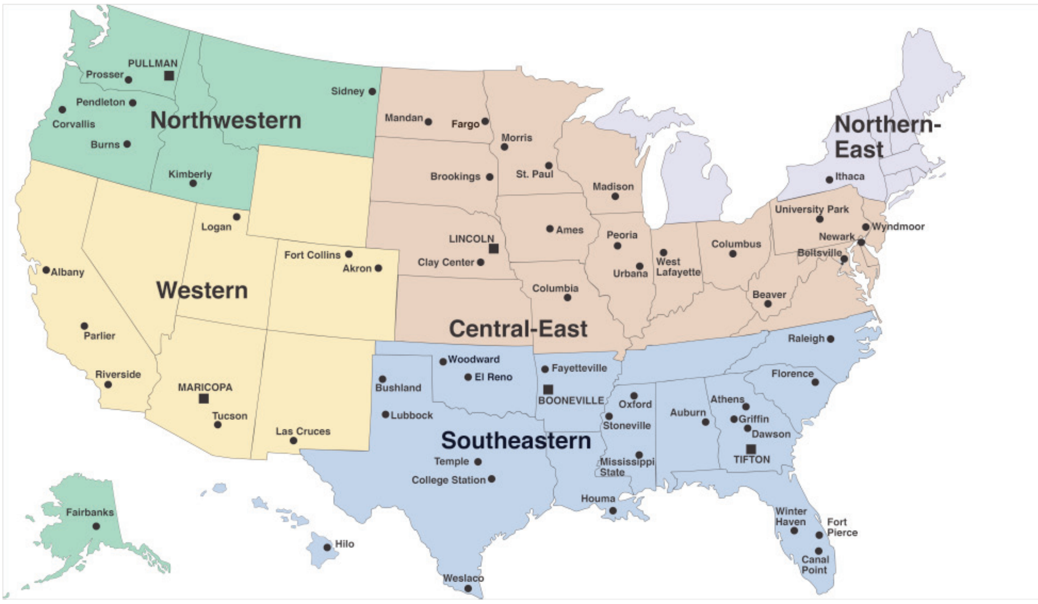

Figure 1: Locations that comprise regional USDA Biomass Research Centers.

The centers focus on feedstock development across the five major regions of the United States. These regions have unique climate and soil characteristics which lead to different capacities to produce biofuel. Of the 79 billion liters of advanced biofuel to be produced by 2022, the USDA estimates that 49.8% will be produced in the southeast, 43.3 % in the central, 4.6% in the northwest, 2.0% in the northeast, and 0.3% in the southwest USA (USDA 2010). The primary focus on biofuel research and development at the Northeastern Biomass Research Center is on woody biomass. The Central-East Biomass Research Center focuses on the development of feedstocks derived from perennial grasses, biomass sorghum, and corn stover. The main emphasis of research at the Southeastern Biomass Research Center is the development of feedstocks derived from energy-cane, sweet sorghum, and perennial grasses. Both the Northwestern and Western Biomass Research Centers focus on woody biomass and industrial oilseed crops. The

Northwestern Center is also examining the sustainability of producing biofuel from post-harvest residues of small grains.

Feedstock for arid and semi-arid crop lands

Arid and semi-arid lands occupy much of the region west of the 100th meridian in the United States. These lands primarily lie within the boundaries of the Northwestern and Western Biomass Research Centers. The major dryland crop grown west of the 100th meridian in the United States is wheat (Fig. 2). Land devoted to dryland cropping in the western United States includes 5 million hectares along the west coast and intermountain west (Schillinger *et al.* 2006) and about 20 million hectares in the Great Plains. Drylands in the Great Plains comprise about 8 million hectares in the northern states of Montana, North Dakota, and South Dakota (NASS 2013); 9 million hectares in the central states of Colorado, Kansas, Nebraska, and Wyoming (Greb 1979); and 3 million hectares in the southern states of Oklahoma and Texas (Baumhardt and Salina-Garcia 2006).

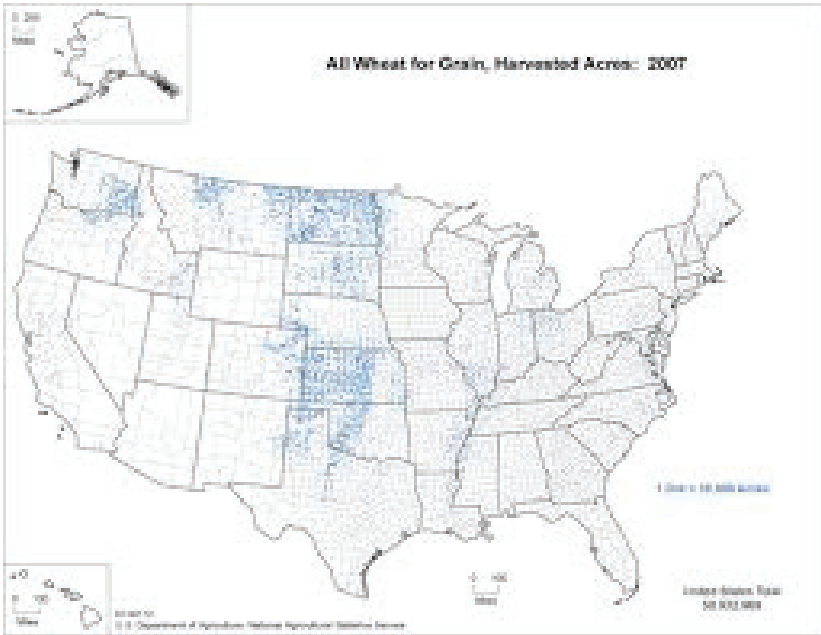

Figure 2: Land in wheat that was harvest in 2007 across the United States.

Dryland cropping systems employed across the western United States are diverse and production is largely dependent on annual precipitation. Along the west coast and intermountain west regions where precipitation is <300 mm, the conventional rotation is winter wheat – summer fallow. In wetter areas where annual precipitation is about 300 to 450 mm, the common crop rotation is winter wheat – spring cereal – summer fallow. In areas of these regions where annual precipitation is >450 mm, the common rotation is winter wheat – spring cereal or winter wheat - legume (Schillinger *et al.* 2006). In the Great Plains, the most common crop rotation is wheat – summer fallow (Lyon and Peterson 2005). Spring wheat is typically grown in the northern Great Plains while winter wheat is grown in the central and southern Great Plains (Hansen *et al.* 2012). Adoption of reduced-tillage practices to control soil erosion has diversified and/or intensified cropping systems over the past two decades across the central and northern Great Plains. Annual spring wheat or spring wheat – spring legume or spring wheat - oilseed are common rotations now used in the northern Great Plains while winter wheat – corn – summer fallow, winter wheat – corn – millet – summer fallow, or continuous cropping are common rotations now used in the central Great Plains (Hansen *et al.* 2012).

Due to precipitation deficits in the western United States, biofuel is anticipated to be produced from a limited number of agricultural feedstocks including crop residue, grasses, and oilseeds. Crop residue is not sufficient to be utilized as both a feedstock for biofuel and as a resource for controlling soil erosion and maintaining or improving soil quality across much of the western United States. In the Pacific Northwest, for example, removal of crop residue may only be sustainable for biofuel production where continuous crops are grown using no tillage (Machado 2011). Although Banowetz *et al.* (2008) found the quantity of cereal residue greatly exceeded that required to maintain soil quality across portions of the Pacific Northwest, Huggins (2010) suggested that soil quality may be compromised when residue is removed from lands that are managed using rotations that include legumes, which produce little residue, or from positions on the landscape which inherently result in poor crop performance. Grass production is an important industry in the Pacific Northwest and accounts for 80% of cool season grass seed produced in North America. The two main areas of dryland grass production in the Pacific Northwest are in the Williamette Valley of Oregon and across the Palouse landscape of northcentral Idaho and southeastern Washington; grass seed is produced on about 160,000 hectares in the Williamette Valley and 15,000 hectares across the Palouse (Edminster 2013). Although area is limited, residue remaining after seed harvest may be a viable feedstock for biofuel because burning is the conventional practice now employed to manage residue and control pests in grass fields. Along the western region of the Great Plains, the small amount of crop residue produced under limited precipitation is important for maintaining soil quality and reducing erosion. In the eastern region of the Great Plains, a portion of the residue produced by the crop may be available as a feedstock for biofuel production (Johnson *et al.* 2011).

A large fraction of biofuel derived from agricultural products is anticipated to come from oilseed feedstocks in the western United States. The Northwestern and Western Biomass Research Centers have therefore been designated as lead Centers for developing oilseed cropping systems for bioenergy. Seed from oilseed crops have the highest energy content of all agricultural crops. Oilseeds, however, are not currently grown across extensive areas of the western United States. Oilseed crops such as canola and sunflower have been grown with success in the west, but their widespread absence from cropping systems is largely due to small or niche markets. Other drought-tolerant oilseed crops such as camelina have the potential of being grown in the western United States. Adoption to the region, however, will require agronomic or rotational practices and development of high yielding cultivars. The goal of the research to be conducted at these centers is to develop the knowledge and technologies required to successfully grow and enhance the oil content, quality and yield of oilseed crops and identify economically viable cropping systems that protect environmental resources. This research will result in new oilseed cultivars that enhance crop performance in the field and the conversion efficiency to biofuel; new strategies for growing oilseed crops in rotation with conventional crops that aid in diversifying and enhancing farm economies; management strategies to control pests in more diverse crop rotations that include oilseeds; crop management systems that more efficiently utilize fertilizers and reduce loss of nutrients to the environment; and tillage and crop management systems that enhance soil quality and reduce emissions of greenhouse gases and particulate matter from farm lands.

Oilseed feedstocks

Numerous oilseeds have potential to be or are currently grown in arid and semi-arid regions of the western United States. These include camelina, canola, crambe, flax, mustard, rapeseed, safflower, and sunflower. Soybean is the most common oilseed crop grown in the United States and accounts for 75% of the nation's crop oil production, but production is restricted to the eastern humid and sub-humid region (Fig. 3). The choice of oilseed to be used as a feedstock depends largely on oil quality and yield, potential uses of the oilseed meal and other by-products, markets, and price and risk support programs. Oilseed crop choice may also depend on benefits or harm to subsequent crops in rotation, particularly for those cropping systems in which oilseeds are of lesser economic value than other crops in rotation. In the western United States where wheat is the major economic crop, for example, oilseed crops are sought which consume little water and provide alternatives in controlling pests.

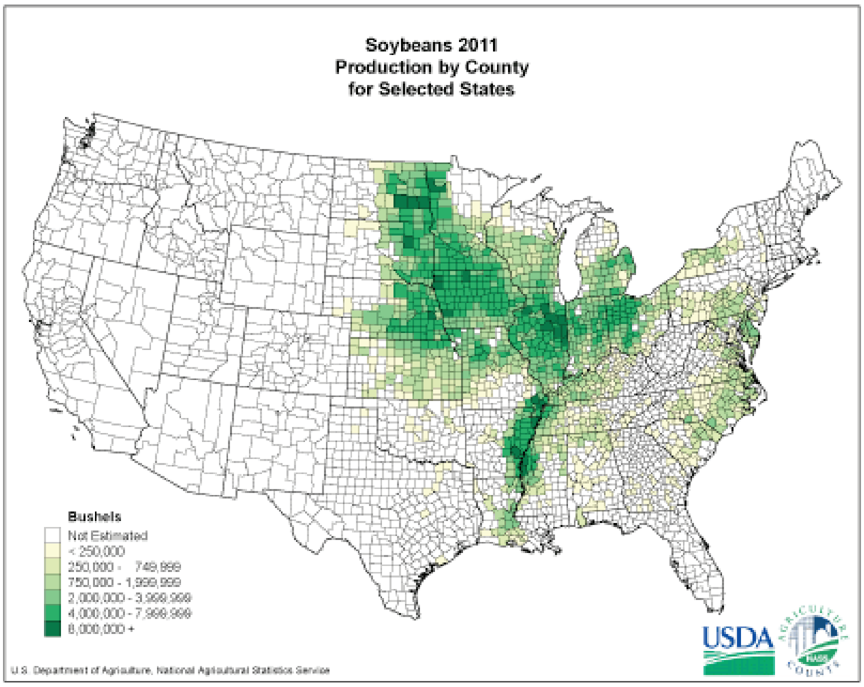

Figure 3: Soybean production across the United States.

The content and quality of oil extracted from seeds varies across oilseed crops (Table 1). Oil quality largely determines usage of the seed for human consumption or industrial applications. For example, oilseeds with low erucic acid (22:1) are desirable for human consumption whereas oilseeds with high erucic acid can be used in industrial applications. Oil quality is also important in the biofuels industry because quality affects the amount of processing and refining required to manufacture fuel. The transportation industry desires a product that can be used as a "drop-in" fuel, or a fuel that is completely interchangeable with petroleum fuel. Drop-in fuels circumvent making substantial changes to engines and the refining and/or distribution infrastructure.

Drought-tolerant oilseeds are best adapted to arid and semi-arid regions. Potential oilseeds for the western United States include those listed in Table 1, except Jatropha and soybean which are native to more humid regions of the world. The use of industrial oilseeds for biofuel avoids the debate over "food versus fuel", or the controversy of using edible oils for bioenergy. For this reason, camelina, crambe, mustard, and rapeseed may be favorable feedstocks. Utilization of the meal after extracting the oil from the seed influences the choice of feedstock since byproducts can bolster revenues. Oilseeds vary in glucosinolate content and thus affect the quality of the meal. Meal containing low (e.g. camelina and canola) rather than high glucosinolates (e.g. crambe, mustard, and rapeseed) are preferred as animal feed.

Table 1: Oil content and fatty-acid composition of selected oilseeds (Abbott *et al.* 1997)

Oilseed crop	**Oil content (%)**	**Fatty-acid composition (%)**										
		16:0	**18:0**	**20:0**	**22:0**	**18:1**	**20:1**	**22:1**	**24:1**	**18:2**	**20:2**	**18:3**
Camelina	33	6	3	2	1	14	15	3	1	19	2	34
Canola	42	4	1	0	0	65	1	0	0	20	0	9
Crambe	41	2	1	1	2	18	4	55	2	9	0	6
Flax (Linseed)	33	6	4	0	0	24	0	0	0	15	0	50
Jatropha	40	10	6	0	0	26	0	0	0	56	0	2
Mustard, Indian (*B. juncea*)	33	3	1	1	1	15	10	40	2	17	1	9
Mustard, Yellow (*B. hirta*)	22	3	1	1	1	16	7	50	2	10	0	9
Rapeseed (*B. napas*)	38	3	1	1	1	14	9	50	1	12	1	7
Safflower (Oleic)	26	5	2	0	0	9	0	0	0	84	0	0
Soybean	22	5	2	0	0	56	0	0	0	37	0	0
Sunflower	46	7	5	0	0	22	0	0	0	65	0	0

Biofuels produced from oilseed feedstock are currently being used by the transportation industry. Camelina has been used, for example, in automobiles (Weaver 2012) and airplanes (Paur 2011). Other oilseeds used by the transportation industry include canola in trains (Vestal 2008) and coconut (Dunn 2008) and Jatropha (Kanter 2008) in airplanes. Although engines have performed satisfactorily using biofuel produced from oilseed feedstock, many barriers yet remain in achieving production goals as set forth by the Energy Independence and Security Act of 2007. These barriers include development of the infrastructure to manufacture and deliver biofuel and increasing oilseed production. Little experience in growing oilseeds in rotation with conventional crops in the western United States impedes adaptation and production. Therefore, for a successful oilseed industry, new knowledge must be acquired concerning performance of oilseed crops, agronomic practices for bolstering production of oilseeds and rotational crops, and environmental resource constraints in growing oilseeds.

Challenges in oilseed feedstock development and production

The USDA anticipates that 5% of the 79 billion liters of advanced biofuels to be produced in 2022 will be in part derived from oilseed feedstocks grown in the western United States (USDA 2010). The enormity of this challenge is apparent given current oilseed yields (Table 2). For example, assume an oilseed crop produces on average 1120 kg ha^{-1} of seed with an oil content of 35% (Table 1) across the western United States. Based upon an oil extraction and processing efficiency of 90%, approximately 10 million hectares or 40% of the total dryland in crop production would be required to produce 4 billion liters of biofuel. This land area devoted to oilseed production could be reduced in half as a result of doubling seed yield.

Table 2: Variation in seed yield of selected dryland oilseed crops across the western United States. Annual precipitation corresponds to the location where the crops were grown

Location	Annual precipitation (mm)	Seed yield (kg ha^{-1})						
		Spring canola	Flax	Camelina	Mustard	Safflower	Sunflower	Crambe
Pacific Northwest[1] (high precipitation)	>450	1120-3360	2240-3360	1790-2470	670-2020	1270-2130	1120-3700	
	<290			130-1150	93-1597	544-1590		
Central Great Plains[2]	420	570-2680					720-2470	640-2710
Northern Great Plains[3]	410	1125-1660	415-1752			458-1367	70-1768	242-2362

[1] data for high precipitation region from Jaeget and Siegel (2008) and data for low precipitation region from Schillinger *et al.* (2007) and Hulbert *et al.* (2012); [2] data from Nielsen (1998) and Stone *et al.* (2002); [3] data from Tanaka *et al.* (2005).

Oilseed yield is greatly affected by precipitation across the arid and semi-arid region of the western United States. This is illustrated by the response in seed yield to the large longitudinal gradient in precipitation that occurs in the Pacific Northwest. Annual precipitation increases from west to east across the Inland Pacific Northwest (or Columbia Plateau region) by 2.5 mm km^{-1}. The response in seed yield of selected oilseed crops to precipitation in the region is illustrated in Figure 4. Seed yields are from varietal trials conducted at multiple locations across the Columbia Plateau. The yield response to annual precipitation was 5.9 kg ha^{-1} mm^{-1} for camelina, 9.2 kg ha^{-1} mm^{-1} for winter canola, and 5.5 kg ha^{-1} mm^{-1} for spring canola and rapeseed. Anderson *et al.* (2003) reported similar production functions in the northern Great Plains, ranging from 3.7 kg ha^{-1} mm^{-1} for safflower to 4.5 kg ha^{-1} mm^{-1} for spring canola, 5.4 kg ha^{-1} mm^{-1} for sunflower, and 6.3 kg ha^{-1} mm^{-1} for crambe. In addition, Nielsen (1998; 2008) found production functions ranging from 4.9 kg ha^{-1} mm^{-1} for camelina to 5.4 kg ha^{-1} mm^{-1} for safflower, 5.9 kg ha^{-1} mm^{-1} for sunflower, 7.6 kg ha^{-1} mm^{-1} for crambe, and 7.7 kg ha^{-1} mm^{-1} for spring canola in the central Great Plains.

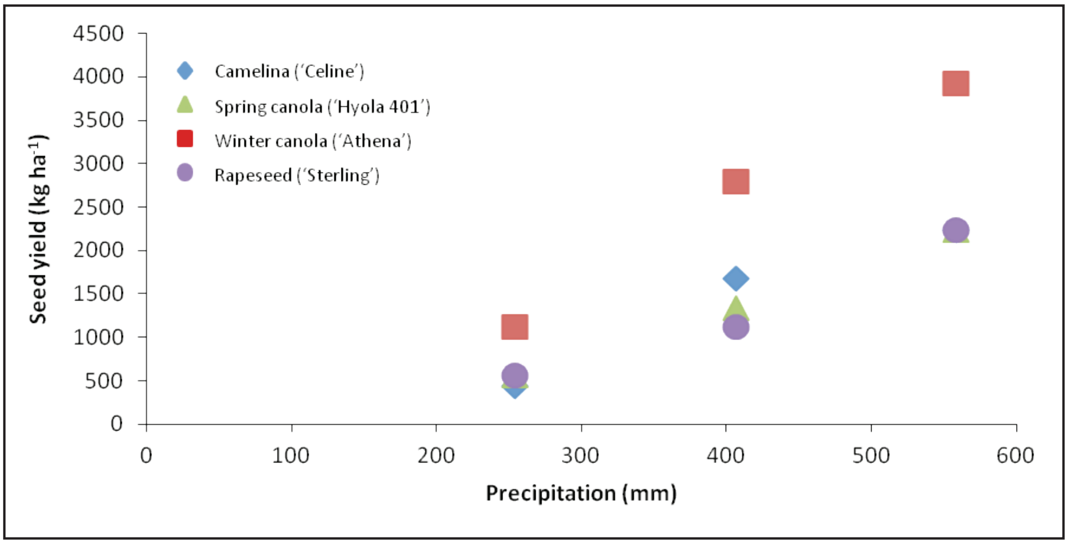

Figure 4: Seed yield as a function of annual precipitation for selected oilseed crops grown across the Columbia Plateau of the Pacific Northwest United States.

Major challenges in the development of feedstocks for the western United States include improving seed and growth characteristics of oilseeds. These characteristics can be improved through traditional and non-traditional breeding methods that increase seed size; reduce seed dormancy; increase oil content; increase tolerance to cold, heat, and drought stress; enhance early-season growth and uniformity in maturity; and reduce seed shattering. Major challenges in the production of feedstocks include the identification of potential production areas. While the data presented in Table 2 are useful in assessing production of oilseeds, replicated field studies across a broad range of environments that include a diversity of oilseeds are needed to better define the potential for oilseed production. Other challenges in the production of oilseeds include determining sowing and fertility requirements; developing conservation tillage and cropping systems for marginal economies; and developing disease, insect, and weed management strategies. In addition, research on production systems must address the environmental effects of cropping systems on greenhouse gas and particulate emissions; wind and water erosion; and carbon sequestration and storage to help develop life cycle analyses.

Progress toward meeting challenges in producing oilseeds

The USDA Biomass Research Centers are actively involved in research to address some of the challenges in developing and producing dryland oilseed crops as a biofuel feedstock. In the western United States, developmental efforts are underway in screening camelina and canola for herbicide and pest resistance and developing cold-tolerant safflower for autumn sowing. The main focus of research, however, is on production systems. For example, camelina, canola, mustard are being tested in varietal trials and better techniques are being developed to establish camelina and canola to enhance winter survival and oil quality and yield in the Great Plains and Pacific Northwest. In addition, management practices are being identified that reduce pest infestations and enhance air, soil, and water quality. A more basic understanding of oilseed thermal and water requirements is being developed for aiding in defining production regions. As a technique to bolster biofuel production in conventional cereal cropping systems, double cropping oilseed with a legume in a winter wheat-legume rotation is being examined in the Pacific Northwest. Markets for seed and meal are limited across the western United States. To enhance the economic benefits of growing oilseeds, alternative uses of the seed meal are being explored in the agricultural industry. For example, camelina, canola and mustard meal are being tested as possible amendments for improving nutrient cycling in soils while canola and mustard meal are being tested as a possible biofumigant in soils.

The USDA Biomass Research Centers have developed partnerships with other federal and state agencies, universities and industry to address immediate challenges of producing biofuel for the transportation industry. In 2010, the USDA established a partnership with the Department of Navy to help bolster the commercial production of advanced biofuels and other renewable energy systems in Hawaii. The need for biofuel is driven by the Navy's ambitious goal of deploying ships and planes powered with renewable fuels by 2016. The USDA also established a partnership with the Federal Aviation Administration in 2010 to develop aviation fuel from biomass. A large market currently exists in the aviation industry for oilseed feedstock. This market is largely driven by the goal of achieving carbon neutrality by 2020 and reducing by 50% the use of petroleum jet fuel by 2050. Fuels have become the single largest operational cost to the airline industry and military in the United States and drop-in fuels are the only choice to reduce costs.

The Biomass Research Centers have also formed a partnership with universities and the fuel industry to accelerate the development of feedstocks for the aviation industry. The primary focus of this partnership is on spring and winter types of camelina and canola. Of interest is enhancing oil quality and yield from these oilseeds, developing cost-effective processes to remove feedstock oil impurities, optimally configuring conversion technology for genetically-improved oilseed feedstocks, identifying co-product market opportunities, and assessing sustainability for expanding oilseed-based jet fuel production

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Drylands and food security in changing climates: an analytical study of Pakistan

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Abstract

Pakistan's sheer vulnerability to climate change, increasing demand for food grains to feed its growing population, variation in topography and changing cropping patterns earnestly call for the need to adopt innovative and fruitful policies to combat with the food insecurity and climate change issues in the country. Viewed in the context of climate change and its sordid effects, achieving food security is a very big challenge. Countering this very challenge has become even more difficult in dryland areas. This paper suggests climate change integrated adaptation and mitigation policies in dry lands to ensure food security for the rising population.

Introduction

Pakistan's sheer vulnerability to climate change, increasing demand for food grains to feed its growing population, variation in topography and changing cropping patterns earnestly call for the need to adopt innovative and fruitful policies to combat with the food insecurity and climate change issues in the country.

Pakistan is ranked first out of 10 most affected countries with respect to Global Climate Risk Index for 2010 (http://germanwatch.org/klima/cri.pdf); and out of 105 countries, Pakistan ranks 75th in the Global Food Security Index of 2011 (http://foodsecurityindex.eiu.com/). In Pakistan, dry land areas consist of 53% of the country's total land where more than 30 million people live. These areas are situated in Khyber Pakhtunkhwa, Punjab, Sindh, Balochistan and Gilgit-Baltistan provinces. Most of the people living in dry lands eke out their livelihood from agriculture and its allied activities.

Dry land farming faces daunting problems of soil erosion, and drought/ water stress due to untimely or inadequate rainfall and high evaporation. All these factors in addition to small land holdings contribute to low and unstable agricultural yield which leads to food insecurity nationwide. Viewed in the context of climate change and its sordid effects, achieving food security is a very big challenge. It should be kept in mind that food security exists when all people, at all times, have nutritious food that meets their dietary needs and food preferences for an active and healthy life. Such a holistic view of food security depends on availability, affordability and accessibility to food. Countering this very challenge has become even more difficult in dryland areas. The many impacts of changing climate on food security in dryland areas have received contemplations in Pakistan due to its close link with rising poverty and sagging economic conditions.

This paper focuses on prevailing scenario and future trends of climate change, food security and agricultural practices in dry land areas of Pakistan. Study also suggests climate change integrated adaptation and mitigation policies in dry lands to ensure food security for the rising population.

It also suggests adopting people-centered development approach to minimize the adverse effects of climate change by enhancing individual as well as institutional capacity building.

Climate change in Pakistan

The phenomenon of Greenhouse Gases (GHGs) has occurred ever since the universe came into being. The Industrial Revolution's anthropogenic activities, namely, power generation from fossil fuels and deforestation activities, have been continuously increasing the atmospheric concentration of GHGs beyond their permitted limits. These have resulted in an enhanced greenhouse effect, that is to say, an increase in global temperature. No country in the world is immune to GHGs, including Pakistan.

Pakistan's vulnerability to climate change is comparatively high as it is situated in a region where the occurrence of temperature increases is expected to be higher than global averages (Chaudhary *et al.* 2009). Its land area is mostly arid and semi-arid. About 60 percent of the area receives less than 250 mm rainfall annually and 24 percent receives 250-500 mm. Its rivers are predominantly fed by the Hindu Kush and Karakoram-Himalayan glaciers, which are reported to be receding quickly due to global warming. Pakistan's economy is largely agrarian and hence highly sensitive to climate. Due to larger risk of variability in monsoon rains, floods and extended droughts are likely to be experienced. Accounting for all these factors, food security in Pakistan is a serious threat (GOP 2010).

Pakistan's status as a GHG emitter

In the year 2008, Pakistan's total GHGs emissions were 309 million tons (mt) of carbon dioxide (CO_2) equivalent, comprised of 54 percent CO_2, 36 percent methane, 9 percent nitrous oxide and one percent other gases. The biggest contributor to this GHGs production is the energy sector, with 50 percent, followed by the agricultural sector's 39 percent, industrial processes 6 percent while other activities' share is 5 percent (GOP 2010).

Table 1: Comparison of different countries on the basis of their per capita energy consumption, per capita CO_2 emission from fuel combustion and ratio of CO_2 emission from fuel combustion to energy consumption (2004): info@pecongress.org.pk

Country/Region	Per capita energy consumption (toe/capita)	Per capita CO_2 emission(tCO_2/capita)	CO_2 emission per unit energy consumption (tCO_2/toe)
World	1.77	4.18	2.37
South Asia	7.91	19.73	2.49
OECD	4.73	11.09	2.34
China	1.25	3.66	2.93
India	0.53	1.02	2.40
Pakistan	0.49	0.76	1.56
Bangladesh	0.16	0.24	1.47

Source: GOP (2010).

The total GHGs emissions of Pakistan in fiscal year 1994, as reported in the Initial Communication (INC) to UNFCCC, were 181.7 mt of CO_2. These are estimated to have increased to 309.4 mt of CO_2 by 2008. The sectoral breakup and comparison for the two years, 1994 and 2008, are shown in Table 2.

Table 2: Inventories of greenhouse gases in 1994 and 2008

Description	1994	2008	AAGR (%)
GHGs emission from all sectors			
Total GHGs emission (mt of CO_2 equivalent)	181.7	309.4	3.9
Total GHGs emission per capita(kg of CO_2 equivalent)	1541	1922	1.6
Total GHGs emission per 1000 US$ of year 2008 (kg of CO_2 equivalent)	2209	1942	-0.9
GHGs emission from fuel sector only			
Total emission GHGs emission from fuel combustion activities (mt of CO_2 equivalent)	78.9	152.1	4.8
Total GHGs emission per capita from Fuel Combustion Activities (kg of CO_2 equivalent	669	945	2.5
Total GHGs emission from Fuel Combustion Activities per 1000 US$ of year 2008 (kg of CO_2 equivalent)	959	955	-
Population growth and gross domestic product (GDP)			
Population (million)	117.9	161.0	2.2
GDP (billion US$ in 2007-08 prices)	82.3	159.3	4.8

Source: GOP (2010)

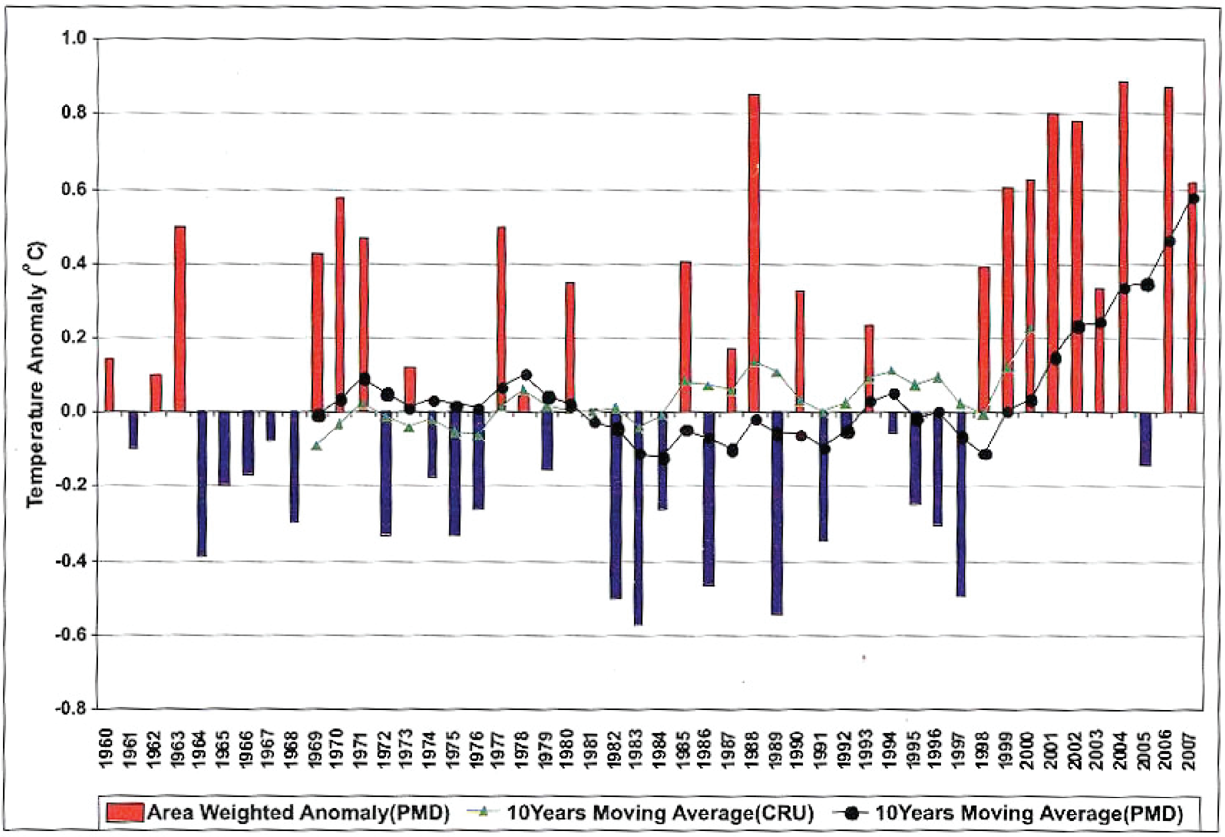
Past and future climate change observations in Pakistan

The studies conducted by Global Change Impact Studies Center (Iqbal *et al.* 2009a) and Pakistan Meteorological Department (Chaudhary 2009; Chaudhary *et al.* 2009) revealed the following trends in annual patterns of temperature and precipitation over the last century, and seasonal patterns of temperature and precipitation over the 50 years period 1951-2000.

- **Temperature:** The averaged mean annual temperature in Pakistan increased by 0.57 ^{0}C over the period, 1901-2000.
- **Precipitation:** The area averaged mean annual precipitation over Pakistan has increased by 25 percent during the last century.

Temperature indicators

Figure 1 depicts the area-weighted mean annual temperatures of Pakistan from 1960-2007, calculated from thirty eight synoptic stations of PMD across the country. The anomaly was plotted along with 10 years moving average of anomalies obtained from CRU data, as described earlier. The time series from both observed data sets have correlation of ~ 0.9 for the period 1960-2000. As seen, the decadal averages of both the data sets follow the cycles of warming and cooling in the same years.



Source: Pakistan Metrological Department, Technical Report No. PMD 22/2009.

Figure 1: Area-weighted mean annual temperature over Pakistan.

According to PMD observed data, the mean annual temperatures over Pakistan have been less than that of CRU observed data. The data has showed a significant rise in mean temperature from 1998. The mean temperatures have risen at the rate 0.099 ^{0}C per decade from 1960-2007 resulting in a total change of 0.47 ^{0}C, which is significant at 95 percent level. The warmest year in Pakistan recorded by PMD was 1988 and the second warmest year was 2002. There was a drastic rise in temperatures in the last decade. Mean temperature anomaly rose to 0.8 ^{0}C and then it started downward trend in the last five years. The average anomaly (1961-1990) normal in the last decade remained 0.4 ^{0}C.

There has been a warming trend in the mean temperatures of Balochistan, Punjab and Sindh provinces in the period 1960-2007, significant at a 95 percent level. The total change in the period was 1.15 ^{0}C, 0.56 ^{0}C and 0.44 ^{0}C respectively (Table 3). A non-significant change, though the trend was rising, was observed in Azad Kashmir, FANA and NWFP. The total change was 0.3 ^{0}C, 0.16 ^{0}C and 0.15 ^{0}C respectively.

Table 3: Change in area-weighted annual mean temperature (^{0}C)

SSr. No	Area	1960-2007
01	Balochistan	1.15±0.25
02	KPK	0.15±0.24
03	Punjab	0.56±0.25
04	Sindh	0.44±0.20
05	Azad Kashmir	0.30±0.27
06	FANA	0.16±0.27
07	Pakistan	0.47±0.21

Source: Pakistan Metrological Department, Technical Report N0.PMD 22/2009.

Precipitation indicators

At the country level, 18 stations with long term data from 1901-2007 and 5 stations data from 1914-2007 were used in the study. Chaudhry (2009) had found an increasing trend in average precipitation for the period 1901-2007 (Figure 3). The analysis showed a total change of about 61 mm. The 10 years moving average showed that rainfall had decreased gradually from the early 1900s to 1940, from 600 mm average to less than 400 mm annually. Since the 1940s the net trend of precipitation was increasing by a total change of 133 mm. The analysis of precipitation was also carried out on a provincial level.

Dryland agriculture in Pakistan: current status and vulnerability

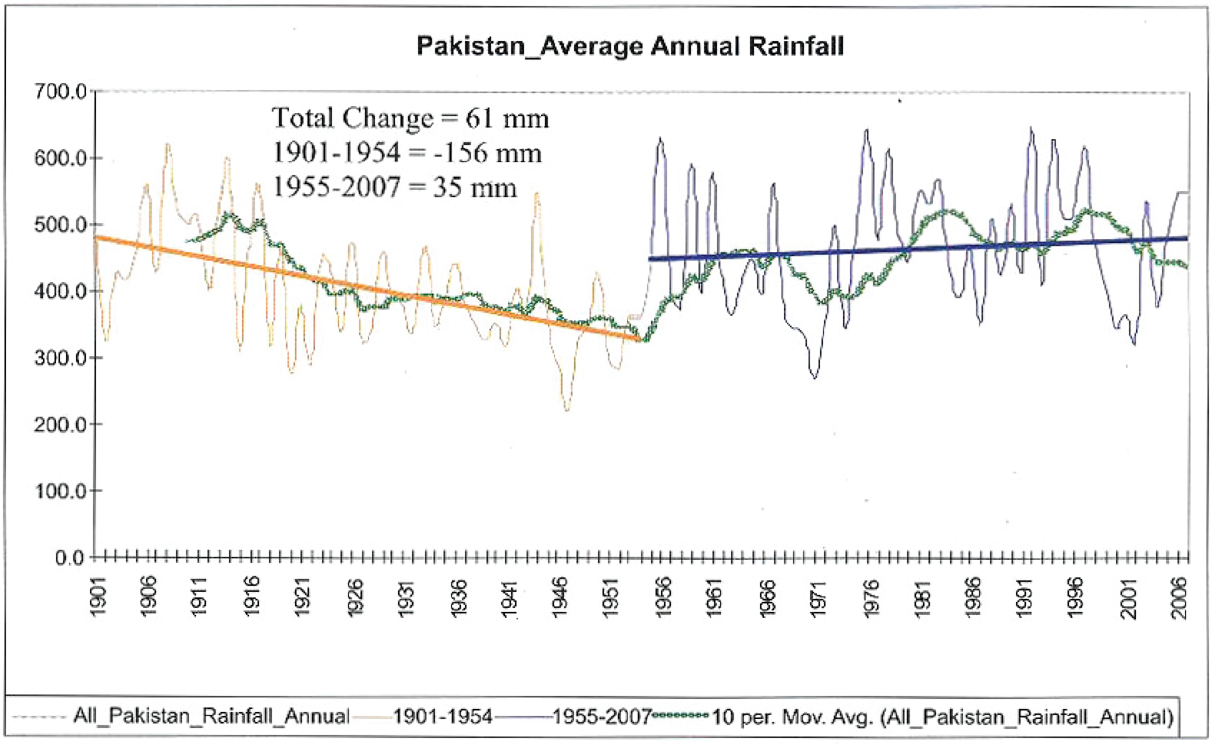
As mentioned earlier, Pakistan ranked first out of 10 most affected countries with respect to Global Climate Risk Index for 2010. Depending upon natural resources, the agricultural sector is more vulnerable to vagaries of nature. The many impact on the agricultural sector due to climate change received high contemplations in Pakistan due to its close link with food security and poverty of a vast majority of the country's population. Most of the agricultural farmlands of Pakistan are classified as arid and semi-arid (Table 4, Fig.4). Almost 68percent of the total geographical area of Pakistan lies under annual average precipitation of 250 mm. (http://www.pakistaneconomist.com/issue2000/issue17/i&e1.htm).

The agriculture and livestock sector has been the mainstay of Pakistan's economy. It contributes 22 percent to gross domestic product (GDP), accounts for 60 percent of the country's exports, provides livelihood to about 68 percent of the country's population living in rural areas, and employs 43 percent of the total labor force. Its foremost challenge is to provide adequate food for the population, which is currently growing at 2 percent annually, without irreversibly damaging the fragile ecosystem. Agricultural activities are by definition highly vulnerable to climate change.

Crop sector: food and non food

The crop sector contributes 10.5 percent to the GDP (food crops: 6.6 percent; fiber crops: 2.5 percent; others: 1.3 percent). The main food crops are wheat and rice with respective shares of

60 percent and 25 percent in the total food crops component of GDP. Cotton and rice are the main cash crops which earn foreign exchange. Most of the farm lands are divided into small sub-economic land holdings. Farmers with only 5 ha or less land account for 86 percent of the farms and 44 percent of farm area in Pakistan. These small farmers are most vulnerable to impacts of climate change as they lack the requisite financial resources and access to information needed for adoption of the latest farm technology. About 38 percent of the cultivated land in Pakistan has already been suffering from environmental damage. Climate change will also aggravate the soil degradation processes in both intensity and the extent, thereby adversely affecting productivity.



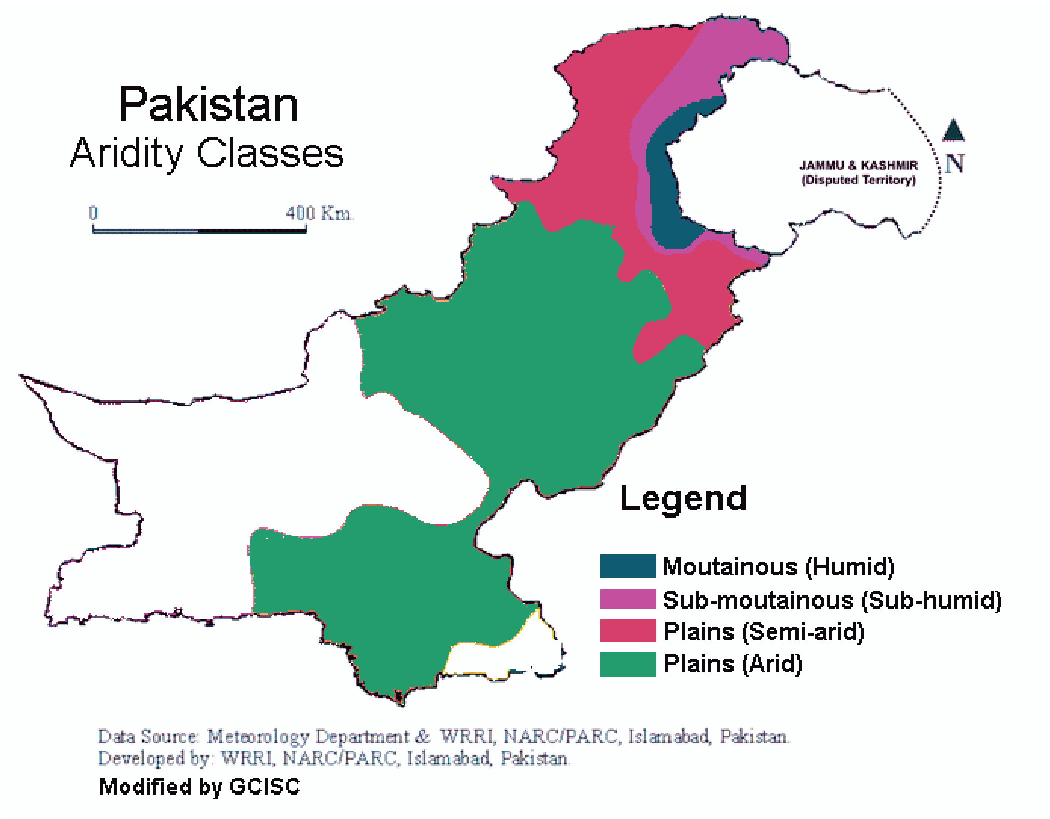
Source: Pakistan Metrological Department, Technical Report N0.PMD 22/2009.

Figure 3: Annual average rainfall of Pakistan (1901-2007)

Table 4: Drylands of Pakistan based upon aridity index (AI)

Area	Rainfall regime	Million ha	% of total
Total Area	<150>1,000mm	79.61	100
Semi-arid	250-500mm (AI 16-31)	8.76	11
Arid	150-250 mm (AI 8-16)	38.21	48
Hyper -Arid	<150mm (AI <8)	26.27	33
Note: AI = ∑1.65(precipitation/Temperature+12.2)x0.9			

Source: Iqbal *et al.* (2009 a)



Source: Sheikh *et al.* (2011).

Figure 4: Agro-climatic zones of Pakistan based on aridity classes.

Crops are particularly sensitive to changes in temperature, ambient CO_2 concentration, precipitation and availability of irrigation water. Given that Pakistan has such a varied climate, ranging from sub-zero temperatures in the north to above 50 ^{0}C in the south, the impact of climate change on crops will be broad. It was found that the length of the wheat growing season will decrease with an increase in average temperature in all the agro-ecological zones in Pakistan, the rate of reduction being larger in the mountainous regions than in the arid and semi-arid plains (Iqbal *et al.* 2009b). For the temperature increases in the range1-5 ^{0}C, wheat yield is predicted to increase in the mountainous regions but decrease in the sub-mountainous, arid and semi-arid regions. The increase in CO_2 concentration will have a positive effect on wheat yield in all the regions due to the fertilization effect of $CO_{2,}$ which could compensate for the adverse effect of rising temperature, though only to a certain extent. With an increase of ambient CO_2 from the current level of 380 ppm to 550 ppm, the baseline wheat yield in the arid and semi-arid plains could be sustained for temperature increases up to 3 ^{0}C (Iqbal *et al.* 2009b).

The length of the basmati rice growing season cultivated in the semi-arid plains of Punjab is also predicted to decrease with temperature rise (Iqbal *et al.* 2009c). At the current level of CO_2 concentration, the yield of rice will have a decreasing trend with the rise in temperature, but increase in the CO_2 concentration level will be helpful in reducing the negative effect of temperature rise.

Status of food security in Pakistan

Food security is a basic human right as stated by the Committee on Economic, Social and Cultural Rights, United Nations (1999): *"The right to adequate food is realized when every man, woman and child, alone or in community with others, has physical and economic access at all times to adequate food or means for its procurement"* .

Since agriculture is highly weather-dependent activity, any change in climate directly affects its performance. There have been essentially two types of climate change affects. One is due to the increasing frequency of extreme climate events such as floods and drought and the other is due to gradual changes in climate such as increase in temperature and precipitation. Both these have far reaching implications on the food security of the country, mainly through reduction in crop productivity and adverse impacts on livestock health (GOP 2010).

Due to varied reasons coupled with the lingering effects of climate change, lack of water for agricultural purposes, load-shedding and a sagging economy, the state of food security in Pakistan is deteriorating. Poverty is closely linked to food insecurity. In the dry farmland areas, most of the farmers have small and scattered agriculture lands. Existing water resources in dry farmland areas are under growing threats due to of climate change. Sometime these areas are left with rain as a sole source of water for crops which results into low yield and low income for farmers.

Due to lack of irrigation system and less availability of water in dry farmland, the food crops have lesser yield. On one hand food production remains unstable in dryland areas of the country and on the other side due to low farm income, unemployment and socio-economic factors people do not have access to enough food to meet their dietary needs.

During the last three consecutive years, Pakistan has been hit by unprecedented monsoon rains and floods (extreme climate events). Incidentally, many of the flood victim districts were already vulnerable to food insecurity as depicted in the Table 5.

It is understood that the full potential of technological advancements and necessary improvements may not be achievable due to the adverse impacts of climate change.

Simulation modeling studies at GCISC (Iqbal *et al.* 2009b) have shown that wheat production in 2080s, under the influence of the climatic factors of the IPCC high- and low- scenarios A2 and B2, will be 6-8 percent lower than the potential production if the climate were to remain unchanged. Rice, the other major food as well as foreign exchange crop, will be more sensitive to climate change (Iqbal *et al.* 2009c). It is predicted that 2080s basmati rice production in Pakistan will likely to suffer an estimated reduction of 15-18 percent due to climate factors anticipated under the A2 and B2 scenarios. These findings will have very serious implications on the food security of Pakistan in the future.

An increase in the frequency and intensity of precipitation events involving heavy rainfall within short periods of time are expected from climate change. Intensive rainfalls will result in damage to crops and loss of top soil. Increased crop production losses coupled with those resulting from the expected more frequent and more intense droughts caused by changes in average values of climatic parameters will further aggravate the food security in Pakistan (GOP 2010).

Table 5: Comparison of food-insecure districts and flood victim districts: Pakistan Floods 2010

Provinces	**Severely effected**	**Moderately effected**
AJK	Muzaffarabad, Neelum, Sudhanutti	Bhimber Hattianbala, Bagh, Mirpur
Balochistan	Jhal magsi, Kohlu, Jarffarabad, Nasirabad, Sibbi, Barkhan, Kech	Zhob, Loralai, Harnai, Lasbela
Gilgit Baltistan	Ghizar, Gilgit, Diamer, Hunza, Nagar	Ghanche, Skardu
KPK	Sawat, Nowshera, Upprt Dir, Kohistan, Shangla, Tank, DI Khan, Charsadda,	Rest of the part of KPK was moderately effected
Punjab	Rajanpur, DG Khan, Layyah, Bhakr, Rehim Yar Khan, Mianwali ,Muzaffargrah,	Multan, Khushab
Sindh	Khairpur, Dadu, Larkana, Thatta, Jacobabad, Kashmore, Sukkur, Ghotki ,Noshero Feroz, Shikarpur	Tando Allahyar, Qambar, Shahdadkot, Jamshoro, Hyderabad

Note: districts in bold are food-insecure districts.
Source: Mahbub ul Haq Human Development Centre (2011).

Adaptations in agriculture for climate change

Agriculture in Pakistan has up till now not been drastically affected by climate change. The extreme events of climate such as floods and excessive rains have had localized effects but overall agricultural productivity has not been significantly affected. Flood control is essentially a management issue and gets aggravated in the prevalent weak governance environment. Many of such calamities can be overcome if a serious effort is made to construct more water reservoirs (Kamal *et al.*2012).

The long term effects of climate change namely increase in temperature and atmospheric CO_2 content and decrease in irrigation water availability are being taken care of by agricultural scientists by developing crop varieties, especially of wheat, which are having drought and salinity tolerance. For this purpose an idiotype of all important crops has to be developed to overcome possible effects of climate change. Modern biotechnology has immense potential in contributing to the development of drought and salinity tolerant crops. Scientists at the National Institute of Biotechnology and Genetic Engineering (NIBGE) and the Centre of Excellence in Molecular Biology (CEMB) of Punjab University, Lahore have advanced programs for developing drought resistant crops of wheat and cotton.

Water has been the most important concern especially for dryland agriculture. Our prevalent methods of irrigation, both in drylands or assured moisture supply areas, are not only obsolete but also most wasteful. It is not possible under the water scarcity scenario to continue with such practices. For this purpose a few years back the Government of Pakistan launched a megaproject to introduce High Efficiency Irrigation System (HEIS) based on subsurface and trickle irrigation technology. A liberal subsidy to farmers is being provided. In private sector many of the irrigation companies are active in popularizing this technology. Such technologies are well suited for drylands where water is scarce and will greatly help in crop diversification.

In Baluchistan, there are ongoing projects on establishing check dams for recharging the aquifer. It is an alarming situation in Quetta where underground water has receded to more than 1000 feet. Efforts are also being made on employing various techniques for artificial recharge of the aquifer. In this connection, rainfall harvesting technology is also being employed. This has been quite effective in the deserts of Cholistan.

It has been a continuous effort to have all technologies introduced through community mobilization. Another megaproject launched by the Government focuses on developing Village Organizations comprising of small farmers and they will be helped to adopt all modern technologies.

Conclusion and policy recommendations

Viewed in the holistic context of food security and coupled with the lingering effects of climate change, achieving the cherished goals of sustainable development from socio-economic and environmental effects is a daunting challenge. People, mired in acute poverty, are generally facing the problem of food insecurity and low income. Climate change and variability further aggravate the fragile state of food security. With low incomes, the marooned people during recent floods were left with no money or any other material support to spend on new adaptation for coping up with the climate variability. Many of such situations can be avoided or overcome by smart management and efficient governance.

In order to support these people in distress, as a short term measure, cash for food programs were adopted at federal and provinces levels (Pakistan Bait-ul-Mal, Benazir Income Support Program, Zakat and Usher) to ensure food security for the impecunious strata. The importance of these cash transfer schemes cannot be denied. But, the Government expenditures on safety-net programs in the shape of financial cost put pressure on already fragile financial sector of the country. The need of the hour is to introduce integrated policies for long term sustainable development by focusing on people-centered developments. Integrated policies using all available technologies and use of information technology for knowledge dissemination about climate change/variability, sustainable agriculture practices along-with safety-net support would lead to improve the status of food security in dry farmland areas of the country under climate change.

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Adoption of reduced tillage in dryland regions of northern Iraq and Syria

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Abstract

The agro-ecologies of recent cropping systems in the dryland areas of the Middle East have many similarities to those which prevailed prior to the 1970s in southern Australia. Over the past 50 years Australian farmers have eliminated fallow phases, introduced new crops (e.g. grain legumes, canola), and most importantly, adopted reduced or zero-tillage (ZT) technology which enables earlier sowing, and allows retention of residues from previous crops on the soil surface. During 2005-2012, as part of an ACIAR-AusAID-funded project developing conservation cropping for Iraq, more than 40 adaptive research experiments investigated the suitability of elements of the Australian cropping system to northern Syria and Iraq. It quickly became evident that ZT seeding without prior ploughing produced similar or better crop growth and grain yields than the conventional tillage (CT) system requiring two or three cultivations before sowing. The elimination of ploughing also enabled earlier sowing which resulted in improved water use efficiency and significant yield increases in cereals and legumes in most years. More accurate seed placement and metering with ZT seeders meant seed rates could be reduced. Most imported ZT seeders are heavy, expensive, and complicated to use and maintain, so a number of simple, effective and affordable seeders suitable for small farmers were manufactured in Syria, while in northern Iraq, the focus was on conversion of existing conventional seeders to ZT using parts made locally. Participatory extension groups were established in Iraq and Syria whereby farmers were able to borrow a ZT seeder to test on their farm without making or receiving any payment. In the vast majority of cases, farmers yields were as good, if not better, with the ZT and early sowing system than with fields sown conventionally, and farmers benefited from savings in fuel and labour costs because of the elimination of tillage operations and reduced seed costs. Since 2006/07, the area under ZT has grown from zero to about 30,000ha in Syria and 7,800ha in northern Iraq in 2011/12. Future challenges for conservation agriculture (CA) in this region include the promotion of soil cover and diverse rotations.

Introduction

The agro-ecologies of recent cropping systems in the dryland areas of the Middle East have many similarities to those which prevailed prior to the 1970s in southern Australia. Both regions experience a Mediterranean-type environment with hot dry summers and cool wet winters. Crop rotations were dominated by wheat and barley (although in Australia these were often in rotation with pastures based on subterranean clover) and in low rainfall areas fallow was utilized to conserve soil moisture for the following winter (Burvill 1979). Soils in both regions were typically infertile with poor structure and low amounts of organic matter. Crop residues were overgrazed by small ruminants especially in dry seasons, leading to frequent dust storms and soil erosion. Two or three cultivations were often employed to control weeds and this typically resulted in a three to four week delay after the first autumn rains before sowing commenced. The average grain yields of cereals were around 1.0 t/ha in both systems.

Over the past 50 years Australian farmers have eliminated fallow phases, introduced new crops (e.g. grain legumes, canola), and adopted the widespread use of herbicides which enabled them to plant crops before or soon after the first autumn rains. During the last two or three decades there has also been a dramatic shift towards the adoption of ZT technology with the retention of the crop residues on the soil surface. The adoption of ZT in Australia was driven by the high cost of fuel and labour, a desire to minimize the risk of soil erosion, and also the ability to conserve soil moisture and enable early crop establishment particularly when autumn rains were marginal. The adoption of ZT practices is now widespread across Australia, and in many regions more than 85% of all agricultural land is not cultivated (Llewellyn *et al*. 2012). Australia is now held up as an example of where the principles of CA (i.e. ZT, soil cover, and diverse rotations) have been a success (Kassam *et al.* 2012).

The similarities of environments and crops, and divergence in cropping technologies in these two regions led researchers to ask whether CA practices, especially ZT, could have a role to play in increasing crop productivity and improving farmer livelihoods in West Asia. This paper describes some of the adaptive research, development and extension undertaken by a project funded by the Australian Center for International Agricultural Research (ACIAR) and AusAID. The project had three phases (2005-2008, 2008-2012, and 2012-2015) with the overall aim of promoting conservation cropping technologies in northern Iraq. Most of the research experiments were conducted at ICARDA near Aleppo, and this resulted in significant spill-over adoption within Syria, even though this was not the main target of the project.

Adoption in Iraq and Syria

Civil unrest in Iraq (and later in Syria) made it difficult to undertake research and conduct extension activities, and many farmers and some researchers were skeptical whether crops could be grown in the region without ploughing. Nonetheless, awareness and interest commenced with innovative farmers examining the first field experiments. To the best of our knowledge no farmers were using ZT in Iraq or Syria when the project started in 2005, but since then the area and number of farmers adopting ZT has increased steadily, undoubtedly as a result of the project. Estimates of adoption in 2011/12 were around 30,000ha by more than 500 farmers in Syria and 7,800 ha by around 100 farmers in Ninevah, Iraq (Fig. 1). Recent shortages and high prices of fuel as a result of the conflict in Syria have helped drive adoption, partly out of necessity.

The success of the project can be attributed to three critical strategies: 1) adaptive research to verify and fine-tune the technology for the region, 2) development of small, simple, and low cost ZT seeders, and 3) participatory extension campaigns that enabled farmers to test ZT seeders and the CA packages on their own farms.

Adaptive research

During 2005-2012 more than 40 adaptive research experiments investigated the suitability of elements of the CA system to northern Syria and Ninevah. It quickly became evident that

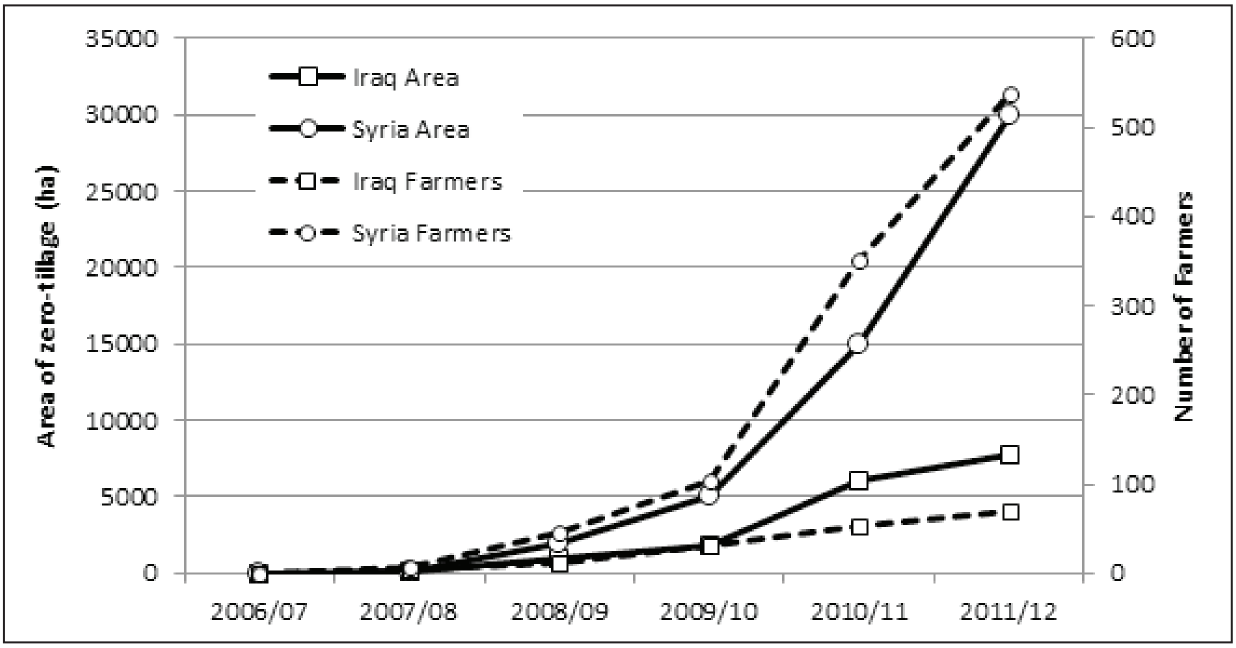

Figure 1: Area and numbers of farmers that adopted ZT in northern Iraq and Syria between 2006 and 2012.

seeding without ploughing resulted in similar or better crop growth and grain yields than the conventional tillage system which required two or three cultivations before sowing. Direct seeding into undisturbed soils enabled early sowing which improved water use efficiency and produced significant yield increases in cereals and legumes particularly when the growing season rainfall was below average (Piggin *et al.* 2011).

More accurate seed placement and metering with ZT seeders also meant seed rates could be reduced. Basic farmer sowing practices (e.g. modified disc plough seeders with little control over seed placement) and poor quality seed, meant farmers had to use seed rates as high as 250-300 kg/ha. In contrast field experiments showed seed rates of 70-100 kg/ha produced the most profitable results over range of seasons when sown with accurate seeders and good quality seed. A reason sometimes used to justify ploughing and removal of crop residue is to avoid the build-up of diseases. However, surveys of nematode and fungal diseases in a number of crops within the long term trials at Aleppo showed no effect of tillage and crop residue, apart from Ascochyta Blight in chickpea which was more widespread but not more severe under ZT (Seid *et al.* 2012).

Zero-tillage seeders

Most imported ZT seeders are heavy, expensive, and complicated to use, maintain and repair, and therefore are unsuitable for small farmers. Hence, the availability of small, simple, and affordable ZT seeders was considered essential if permanent and widespread adoption was to occur. Tined seeders with knife points were favoured over disc machines because of their simplicity and suitability to wide range of soil-types. Local seeder manufacturing capacity was assessed and enhanced with expertise from Australian agricultural engineers, and a number of suitable ZT seeders were manufactured in Syria. In northern Iraq, manufacturing capacity and availability of materials were weakened by on-going conflict and isolation, and the focus of innovative farmers was on converting existing conventional seeders to ZT using knife points made locally and increasing row spacing to 22-30cm (Jalili *et al.* 2011). John Shearer seeders introduced in earlier Australian projects and Rama seeders made in Jordan are popular in Iraq and proved cheap and easy to convert to ZT. In fields with supplementary irrigation there were some difficulties with heavy crop residues causing clumping and blockages of seed and fertilizer, but these were solved by redistributing tines on three rather than two tool bars, and lifting the seed and fertilizer box to allow free flow of seed and fertilizer down the tubes to the furthest tines.

There are currently seven manufacturers of ZT seeders in Syria, and over 70 seeders have been purchased by farmers. Improvements in materials, design, and construction are ongoing. In Iraq about 40 seeders have been converted to ZT and Iraqi farmer-manufacturer groups are involved in on-going development of locally-made seeders, tines and press wheels. In late 2012 the first Iraqi manufactured ZT seeder prototype was completed.

Participatory extension

Once the CA agronomic package was developed and simple and affordable ZT seeders were available, participatory extension groups were established in Iraq and Syria. These groups involved local government, private and NGO researchers and extension officers, manufacturers, and farmers. In most cases a ZT seeder was allocated to a village or group of farmers who were able to borrow it to test on their farm without giving or receiving payment. Each user was encouraged to share experiences and supply information on crop performance from their ZT and conventional fields back to the group. In the vast majority of cases, yields were as good if not better with ZT and early sowing compared to fields sown conventionally, and farmers benefited from savings in fuel and labour costs and time because of the elimination of tillage operations as well as reduced seed costs from lower seed rates. The extension campaign also demonstrated that the package was widely applicable to all soils and seasons, and it was rare for a farmer to try a ZT seeder and not expand the ZT plantings in subsequent years, either by borrowing a seeder or purchasing his own.

The participatory aspect of this campaign was critical to its success and it gave farmers ownership of the ZT demonstrations and direct experience with ZT, early planting and low seed rates in their own fields. The fact that there were no payments, and the participating farmers were investing the majority of the cost (seed, fertilizer, fuel) was not queried nor a constraint for farmers who could see the potential of the technology to increase production, reduce costs, and improve their soils. Many farmers took much pride in presenting and discussing their results at field days and meetings. In an encouraging development in both Iraq and Syria, some farmer groups proud of their achievements and keen to spread the benefits of ZT technology have independently organized and funded their own field days. Other projects where development and extension organizations conducted all operations of the farmer demonstration from start to finish, provided all the inputs, and in some cases paid farmers for use of their land, have been less successful in generating real adoption of new technologies, probably because farmers had less ownership of the activity. As has been experienced in Australia and other parts of the world where CA has been successful (Kassam *et al.* 2012), farmers and farmer organizations are taking a lead in developing and promoting ZT technology in Syria and Iraq in collaboration with researchers and extension organizations. An important development was the formation of the "Mosul Society of Conservative Agriculture", a group of farmers and scientists who encourage and support CA development in Ninevah.

Preliminary socio-economic studies have investigated the impact of the participatory extension campaigns in Ninevah and Syria. In 2011 a survey was conducted of 338 wheat farmers in Ninevah; 35 of these used the conservation cropping package (Abdulradh *et al.* 2012). The average yield of wheat was increased significantly by adopting ZT and the mean level of technical efficiency between farming systems was 87 percent for ZT farms compared to 75 percent for those using CT. The cost of ZT seeder purchase or conversion was highlighted as an obstacle for adoption, especially by small poor farmers. It was suggested that adoption of CA would be enhanced further if government subsidies for inputs such as seed, fertilizer and fuel which tend to promote their overuse were redirected towards reducing the cost of ZT seeders.

Future challenges

The CA package extended in Syria and Iraq deliberately focused on eliminating tillage, adoption of ZT seeders and sowing early with reduced rates of seed. These changes reduced costs (fuel, labour and seed) and provided the greatest immediate increase in yields, and hence were the most attractive to farmers. However, little progress has been made in regard to the other two main objectives of CA, namely maintaining soil cover with crop residues and diversifying crop rotations. This strategy was intentional because promoting the whole CA package including residue retention and diverse rotations to small farmers, many of whom are poor and illiterate, would have been too great a change in one step and the added complexity would have increased the likelihood that something would go wrong with the system. Instead adoption of CA was seen as a process, whereby farmers could take a step at a time when they felt ready.

Crop residues are highly valued in the integrated crop and livestock production systems common throughout Central and West Asia and North Africa (Magnan *et al.* 2012). In dry years, the straw of crops can be more valuable as a stock feed than the grain. In any case, the amount of crop residue produced in these dryland systems is often low and the benefits of crop residues may be relatively small. In an analysis of a long term trial in 2009/10 on a self-mulching clay soils near Aleppo Syria and crop modeling over 30 years of weather data, Sommer *et al.* (2012) suggest there is little benefit in retaining standing stubble in terms of soil water retention and yield.

If farmers want to retain crop residues to benefit soil fertility and moisture retention, fields need to be fenced because many shepherds do not recognize land ownership once the crop has been harvested. One farmer in Ninevah has started a fencing program to effectively manage crop residues. If alternative feed sources were developed and adopted and grazing better controlled, then it is much more likely that crop residues would be retained on the soil surface. Many forage legumes or dual purpose cereal crops have potential, especially for farmers that produce both crops and livestock. The use of palatable perennial species to form permanent alleys in combination with CA cropping in between the alleys could also provide a solution, but again grazing would need to be carefully managed to maintain soil cover. The role and benefits of residues and alternative feed sources need more detailed study in the region, especially where rainfall is low and/or highly variable.

Cropping systems in Central Asia, West Asia and North Africa continue to be dominated by cereals, especially in dry, risky environments. Development and promotion of productive and profitable alternative crop options to diversify rotations would be beneficial to the productivity and sustainability of the whole system. Grain legume crops such as lentil and chickpea should be re-examined more closely, in addition to other crops such as canola which is grown in medium to low rainfall areas of Australia. Government policy has a role to play in regard to alternative crops. Part of the dominance of wheat in some countries can be attributed to governments subsidizing wheat prices in an attempt at enhancing food security, in addition to low productivity and/or poorly developed markets for alternative crops.

On the back on the success of this project, other projects have been recently funded to promote the adoption of CA in Morocco, Algeria, Tunisia, Egypt, Jordan, Lebanon, Turkey and Tajikistan, and there is also much interest from Iran and Sudan. These and other CA projects will benefit from the lessons learnt and the successful strategies used in Iraq and Syria.

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Management of drylands in Kyrgyzstan

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Abstract

The area of drylands makes 40 percent of all arable land in Kyrgyzstan. Thirty percent of cereal crops and 20% of perennial grasses are grown in these areas. The legumes-fallow crop rotation, where the fallow has to make 20% , is base of drylands development. The fallowing permits water conservation, permits nitrogen accumulation in the soil and reduces the problem of weeding. The yield of winter wheat in pure fallow fields increases to 0.5-1.0 ton per hectare. Investigations are being made currently on crop rotation, where legumes crops such as soybean, grasspea, vetches, peas and chickpeas are alternate to perennial crops (alfalfa) and some legumes could replace the fallow phase of the cereal-fallow rotation. Results have shown that when soil moisture is sufficient through precipitations in the dry lands it is possible to replace fallow by a legume crop. Breeding for drought tolerant varieties of winter wheat done in the Republic has resulted in the development of winter wheat Erythrospermum 760', 'Adyr' and 'Kairak'. They are early-maturing and able to form the spike before strong heat. The drought tolerant varieties of spring barley bred are 'Naryn 27', 'Taalay', 'Bestam' and 'Kylym'. The potential productivity of these varieties on drylands reaches 4.0-4.5 ton per hectare.

Introduction

The Kyrgyz Republic is located in the North-East of Central Asia. On three sides, North, West and South, it is bordered by Kazakhstan, Uzbekistan and Tajikistan. From the East and the South-East it is bordered by the People Republic of China. The territory of Kyrgyzstan covers 198.5 thousand km². It is the country of high mountains, average height of its territory being 2750 m, and the highest about 7439 m above sea level. More than 94 % of the Republic's area is located at 1000 m above sea level. Enormous amplitudes of heights, a difficult relief, and long geological development of the country have caused diversity and riches of natural resources. The climate is continental, is affected by aridity, duration of solar light, and altitude and there is big spatial variations. The climatic variation is connected with rather southern location of the country, its remoteness from oceans, the neighborhood with extensive deserts and relief contrast.

The rainfed areas in the Republic make 40 percent of all arable land. Here the main limiting factor of stable crop yield is the atmospheric precipitation. Based on the quantity of precipitation the rainfed lands are divided in to arid (250 mm per year), and semiarid (300-350 mm) lands and those provided with relatively high precipitation (450 mm). Some 57 percent of cereal crops, 20 percent of perennial grasses and 20 percent of fallows are located in the dryland areas.

During the agriculture reforming years (1992-2001) the policy of reducing the arable land by transforming it to other categories such as pastures and long fallow was followed. All this has led to efficiency decrease of rainfed lands.

Research to increase productivity of rainfed cropping

According to results of experiments conducted by Kyrgyz Agricultural Research Institute, the basis of rainfed land's efficiency increase is adaption of a cereal-fallow crop rotation, where the fallow area makes 20 percent. It is basically a 4-course crop rotation: fallow - winter wheat – spring barley - winter wheat.

The fallow allows moisture enrichment of the profile, and saving and accumulation of nitrogen in the soil for use by the cereals in the rotation. Removing weeds is essential during the fallow period. After clean fallow the winter wheat productivity increases to 0.5-1.0 t/ha depending on moisture supply of the year. So, at the precipitation level of 450 mm the yield of winter wheat after fallow has been as high as 5.0 t/ha. At the same time a loss of organic matter in fallow due to high biological activity of rainfed lands has been recorded. For the years of investigations (1990-2005) a humus loss in arable lands of the magnitude of 7.4 t/ha and 8.6 t/ha was recorded in the topsoil.

The soil-protective tillage has great value in the system of rainfed areas. Application of subsurface ripper allows increase in moisture accumulation amounting to 25-40 mm a year. This effect of conservation tillage was noticed under all the crops of the rotation. As an average for 5 years the winter wheat yield on subsurface ripper tillage system was 3 t/ha, spring barley 1.9 t/ha and the second winter wheat 1.4 t/ha. In the years with insufficient rainfall, soil surface tillage treatment with share and disk tools has given positive results. Such tillage promotes the best accumulation of moisture in the tillable horizons. Thus the winter wheat yield increases by 0.4 t/ha in comparison to the tillage with moldboard plough.

The optimum soil moisture accumulation occurs with subsurface tillage treatment of fallow field, shallow tillage treatment under spring barley, and moldboard ploughing under a winter wheat in the four course crop rotation. The best moisture accumulation, in turn, results in higher grain yields. Experiments in the last years have shown higher yields of cereal crops sown by the stubble seeders CZC-2.1. The yield of winter wheat at such sowing increased to 0.3 t/ha in comparison with usual seeder.

The yields of all crops in the cereal - fallow crop rotation depended firstly on the quantity of precipitation, and then on their place in the rotation. In high rainfall years, the top yield of winter wheat was 5 t/ha on lands where the clean fallow period tillage treatment was with subsurface - deep ripper.

Amongst the grain crops cultivated in rainfed zone winter wheat and spring barley provide greatest potential for productivity in cereal - fallow crop rotation. Hence great emphasis has been laid on developing improved cultivars of these crops.

Breeding for drought tolerant cultivars

A major program on breeding drought-tolerant varieties of cereals for rainfed areas has been carried out at the Kyrgyz Agricultural Research Institute. Based on this work the new winter wheat varieties recommended for dry areas include 'Erythrospermum760', 'Adyr' and 'Kairak' of bread wheat. All these varieties are rather early-maturing capable to form a spike before a severe drought sets in. At an Experimental Station of the Institute the productivity of rainfed cereals for last years was 2.7-5.0 t/ha depending on soil moisture sufficiency. These varieties contain 13.8 - 15.3 percent protein and 28.2- 33.7 percent gluten.

In the last few years a new variety of winter wheat 'Ehol', was developed which on state experimental fields has given an yield of 3.9-4.9 t/ha and the grains contain 13.1-15.8% protein and 27.4-29.0 % gluten content. This year (2013) the variety is included into the register of offered varieties for use in the rainfed conditions of Kyrgyzstan.

The main variety of the spring barley cultivated on rainfed areas is 'Naryn 27', which is characterized by high productivity, drought tolerance and the high protein content (15-16 percent). The variety is distinguished by its vigorous growth during the first period of vegetation and its ear formation is 8-12 days earlier than other varieties. This permits it to withstand severe drought. Its potential productivity is 3.0-3.2 t/ha.

New varieties of spring barley have also been bred for their use in rainfed agriculture. These are 'Taalay', 'Bestam' and 'Kylym'. These varieties are of medium maturity group and drought-tolerant. Protein content in grain is 14-15 percent. Potential productivity on rainfed lands provided with sufficient moisture is 4.5 ton/hectare. All of them are well adapted for local soil and climatic conditions of the country.

Fallow replacement to increase cropping efficiency

Introducing suitable crops to replace fallow phase in the rotation increases cropping intensity, allows to realize an additional yield, improves soil chemical properties and, thereby, raises its fertility. Recent investigations on introduction of leguminous crops for fallow substitution have given these results. Introduction of legumes for substitution of fellow gave 0.5-0.8 t/ha additional legume grain yield from the rotation. Ploughing down the leguminous biomass for green manure promoted the soil water use by 55-70 m^3/ha. The humus content of the soil was 10.1-10.76 t/ha which was 4 t/ha more than in crop rotations with clean fallow.

The safflower, peas, chickpea, pea and vetch are recommended as crops for fallow substitution. Leguminous crops not only increase the productivity of crop rotation but also promote enrichment of available nitrogen in the soil that allows production stability of rainfed lands.

The moisture conserved up to a meter depth of the soil was 2060 m^3/ha when subsurface tillage was done in the fallow fields. It increased to 2135 m^3/ha by ploughing in legume straw. When green manuring was done in the fallow phase moisture accumulated was 1850 m^3/ha. In contrast, under the clean fallow treatment it was only 1762 m^3/ha. Moisture conservation during the summer period improved for the fallow with a straw cover by 1539 m^3/ha. Green manure added to moisture accumulation by 1320 m^3/ha.

The winter wheat yield in the four course rotation was 3.7 t/ha when fallow had treatment of legume straw ploughing in. When green manuring was done the yield was 3.1 t/ha. Clean fallow treatment resulted in a winter wheat yield of 2.7 t/hectares. Leguminous crops used to substitute fallow in the rotation gave following yields: peas 1.9 t/hectares, chick pea 1.9 t/hectares, safflower 2.2 t/hectares.

Nitrogen accumulation on rainfed sites depended on quantity of precipitation and cultivated crop. With the introduction of legumes in the fallow phase the nitrogen content in arable horizon increased from 18.9 kg/ha under clean fallow to 51.8 kg/ha under peas and 53.7 kg/ha under chick pea.

Efficiency of cereal-fallow crop rotations with introduction of a crop to replace fallow depended on the crop used for substitution. The addition of leguminous crops increased production of the rotation to 11 t/ha of fodder units with peas and 11.2 t/ha with chickpea. Cultivation of leguminous crops increased the efficiency of crop rotation by 3.1 – 3.9 t/ha fodder units in comparison to clean fallow.

Conclusion

A four course cereal-fallow rotation is widely used on the rainfed areas of the country. The productivity depends on the amount and distribution of rain. Fallow is an important component of the four course rotation because it provides advantage of increased moisture conservation and accumulation of mineralized nitrogen in the soil for the cereal crops. The productivity can be improved by using tillage treatments to improve moisture conservation. The treatments would differ depending on the moisture supply. Direct seeding of cereal seems to be feasible. The research shows that in the moisture sufficient conditions on rainfed lands of the Kyrgyz Republic a replacement of clean fallow by leguminous crops is possible. Under acute deficiency of moisture there is no advantage of this innovation over the clean fallow.

Use of biotechnological tools and novel genetic resources for enhancing resilience of major dryland crops to climate change in dry areas.

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Abstract

Food security for the fast growing population will depend on our ability to produce more per unit area without depleting the resources base, and on facilitated access of population to food commodities. The development of improved varieties with higher and stable yields has contributed to food security for the commodities of global importance such as wheat, rice, maize which are at the origin of the green revolution. Currently the Global wheat productivity is increasing at a rate of 0.9 t/ha. Further genetic gains in yields will depend on access and use of novel genetic diversity and use of biotechnology tools to increase the efficiency of breeding programs. ICARDA has one of the richest collections of cereals and legumes totaling 153,000 accessions composed mainly of landraces and wild relatives which should be mined for useful genes. Introgressions from wild wheat relatives have been important sources of genetic variation: *Sr2*, *1B/1R* and *Lr19* are three examples with major impacts in both the developing and developed world wheat production. Biotechnology has played significant roles in improving agricultural production. For instance, embryo rescue *in vitro* has allowed the development of synthetic hexaploid wheat from crosses between durum wheat and *Aegilops tauschii* which is contributing significantly to enlarge the genetic base of bread wheat. Synthetic hexaploid wheats have enabled to mobilize the wealth of genes available in the D genome progenitor of wheat, *Ae. tauschii.* New alleles are identified in the progenies using molecular markers techniques. Tissue culture is routinely used for the production of doubled haploids in wheat and barley which reduces significantly the time to bread new lines. Diagnostic markers are used in ICARDA mandated crops for marker-assisted selection. For location of genes, quantitative traits loci (QTL) mapping in biparental populations and association mapping in germplasm collections are being used. TILLING populations in various crops have been developed and are being used to identify genes responsible for various different stresses. EcoTILLING is being used to utilize natural variation of known genes. In this paper, different approaches of using biotechnological tools and novel genetic resources for enhancing resilience of major dry land crops to climate change in dry areas are discussed.

Introduction

The world population is increasing at a faster rate and is expected to reach 9 billion in the year 2050 from the current 7 billion. Unlike the times of the Green Revolution, current food production at global level is not increasing at the same pace as the population increament. This disparity is going to be excerbated further with the increasing occurance of drought, heat shock, more aggressive and virulent diseases and pests, increased cost of fertilizers, and other inputs such as herbicides, and irrigation water. Application of new tools such as biotechnology, mining of genetic resources, setting of new collaborations and partnerships and designing of favourable research, development and extention policies, among others, are required to develop climate resilient crops and thereby to increase further genetic gains and food production in order to insure food security.

Mining of genetic resources

ICARDA's genebank holds about 153,000 accessions, representing about 20% of the germplasm in the centers under the Consultative Group on International Agricultural Research (CGIAR). Particularly important are the landraces and wild relatives in these collections as they have evolved under harsh conditions over millennia. Based on detailed eco-geographical characterization, drought- and heat-tolerant genebank accessions, genetic stocks and improved germplasm have been identified and are being tested in field experiments in stress-affected sites as well as under controlled environments. The stress-tolerant sources are being analyzed for genetic diversity and functional diversity at DNA and RNA level. About 11,000 accessions have been characterized using single sequence repeat (SSR) markers, with funding from the Generation Challenge Program of CGIAR. These include 3000 barley accessions (done in collaboration with CAAS, China), 3000 wheat (with CIMMYT), 3000 chickpea (with ICRISAT; Upadhaya *et al.* 2008), 1000 lentil and 1000 faba bean accessions. Reference collections have been extracted of about 300 accessions each of barley, wheat, chickpea and 150 accessions each of lentil and faba bean. These reference collections have been phenotyped to serve as an association mapping panel. Association analyses are being conducted in cases were high throughput genotyping has been carried out. Numerous other genetic diversity studies have been and are being conducted on ICARDA's mandate crops using single nucleotide polymorphisms (SNP), simple sequence repeats (SSR) and amplified fragment length polymorphism (AFLP) markers.

Prospects to assess and explore largely untapped plant genetic resources (PGR) collections to search for agronomically important traits, such as tolerance to abiotic stresses are possible through new approaches such as the Focused Identification of Germplasm Strategy (FIGS). FIGS approach is based on the paradigm that any germplasm is likely to reflect the selection pressures of the environment from where it evolved. The approach uses trait and environmental data (climate including phenology data) to develop *a priori* information based on the quantification of the trait-environment relationship. If a dependency between the trait and the environment is detected, the *a priori* information is then used to define subsets of accessions with a high probability of containing the sought-after traits. The subsets of accessions are then used for *a posteriori* evaluation. Recent research comparing both *a priori* information and *a posteriori* information supports the assertion that FIGS can be used as an effective tool to search for traits of tolerance to abiotic stresses such as drought. The approach has successfully identified novel sources of resistance in wheat to powdery mildew, sunn pest, Russian wheat aphid, and Hessian fly, as well as new sources of tolerance to salinity and drought.

Incorporation of genetic diversity into elite wheat (*Triticum aestivum* L., 2n=6x=42, AABBDD) cultivars has long been recognized as a means of improving wheat productivity and securing global wheat supply (Ogbonnaya *et al.* 2013). Synthetic hexaploid wheat (SHW) genotypes created from its two progenitor species, the tetraploid, *Triticum turgidum* (2n=4x=28, AABB) and its diploid wild relative, *Aegilops tauschii* (2n=2x=14, DD) are a useful resource of new genes for hexaploid wheat improvement. These have many productivity traits such as resistance/tolerance to abiotic (drought, heat, salinity/sodicity, and waterlogging) and biotic (rusts, Septoria, barley yellow dwarf virus, crown rot, tan spot, spot blotch, nematodes, powdery mildew, and Fusarium head blight) stresses as well as novel grain quality traits. Numerous SHWs have been produced globally by various institutions including CIMMYT-Mexico, ICARDA-Syria, Department of

Primary Industries (DPI), Victoria-Australia, IPK-Germany, Kyoto University-Japan, and USDA ARS. It has been demonstrated that synthetic backcross-derived lines (SBLs, i.e., when SHW is crossed to adapted local bread varieties) show significant yield increases and thus enhanced yield performance across a diverse range of environments, demonstrating their potential for improving wheat productivity worldwide. This is particularly evident in moisture limited environments. The use of SBLs, advanced backcross QTL analysis, chromosome introgression lines, and whole genome association mapping is contributing to the elucidation of the genetic architecture of some of the traits. The contribution of transgressive segregation to enhanced phenotypes and the mechanisms including its genetic and physiological basis are yet to be elucidated.

Doubled haploid breeding

Genetic improvement to develop varieties with high yield potential and resistance/tolerance to abiotic and biotic stresses with acceptable end use qualities is the most viable and environment friendly option to increase wheat yield in a sustainable fashion (Tadesse *et al.* 2012). *In vitro* haploid production followed by chromosome doubling greatly enhances the production of complete homozygous wheat lines in a single generation and increases the precision and efficiency of selection process in wheat breeding. It also enables the detection of linkage and gene interactions, estimates genetic variance and the number of genes for quantitative characteristics, produces genetic translocations, substitutions and chromosome addition lines, and facilitates genetic transformation and mutation studies. Wheat cultivars developed from doubled haploids using anther-culture and maize induction systems have been released for cultivation in both developed and developing countries. At ICARDA we produce DH lines of wheat and barley using anther-isolated microspore culture. Between 1000 and 5000 DH lines are produced each year. DH lines are either produced from F_1s, or are produced from selected F_2s and F_3s to develop homozygous lines within 12-14 months. In recent years the technique has been used mainly in spring and winter wheat. In an earlier project ICARDA provided support to ARC in Wad Medani, Sudan to establish a DH system for wheat. A student was trained on the technology at ICARDA, who subsequently successfully transferred the technology to Sudan (Ali *et al.* 2006). From the material developed in 1999/2000 two DH varieties were released in 2005, and are now being grown by farmers in Sudan.

Mutation breeding

A Targeting Induced Local Lesions IN Genomes (TILLING) population has been developed for the barley variety ‘Lux’ (Lababidi *et al.* 2009). A series of pool ratios of mixed DNA from mutant lines were tested and 10-fold pools appeared to be the practical mixing ratio for the detection of fragments in the 500–700 bp range. Two of the 13 known dehydrin genes, *Dhn12* and *Dhn13*, were examined and five independent missense mutations were obtained from a population of 9575 barley mutant plants. Durum wheat variety ‘Omrabi-5’ and bread wheat variety ‘Cham-6’ have been mutagenized with two different doses of ethylmethanesulfonate (EMS). Plant materials have been collected from leaves of each M2 plant to isolate genomic DNA. The isolated DNAs are being used in reverse genetic screening, while the M3 seeds are being used for ‘Forward genetics’ screening.

Xia *et al.* (2012; 2013) have shown that small heat shock protein 17.8 (HSP17.8) is produced abundantly in plant cells under heat and other stress conditions and may play an important role in plant tolerance to stress environments. However, HSP17.8 may be differentially expressed in different accessions of a crop species exposed to identical stress conditions. The ability of different genotypes to adapt to various stress conditions resides in their genetic diversity. Allelic variations are the most common forms of genetic variation in natural populations. Single nucleotide polymorphisms (SNPs) of the HSP17.8 gene were investigated across 210 barley accessions collected from 30 countries using EcoTILLING technology. Eleven SNPs including 10 from the coding region of HSP17.8 were detected, which form nine distinguishable haplotypes in the barley collection. Among the 10 SNPs in the coding region, six are missense mutations and four are synonymous nucleotide changes. Five of the six missense changes are predicted to be deleterious to HSP17.8 function. The accessions from Middle East Asia showed the higher nucleotide diversity of HSP17.8 than those from other regions and wild barley (*H. spontaneum*) accessions exhibited greater diversity than the cultivated barley (*H. vulgare*) accessions. Four SNPs in HSP17.8 were found associated with at least one of the agronomic traits evaluated except for spike length, namely number of grains per spike, thousand kernel weight, plant height, flag leaf area and leaf color. The association between SNP and these agronomic traits may provide new insight for study of the gene's potential contribution to drought tolerance of barley.

Gene identification and mapping

Association mapping studies using elite bread wheat genotypes from ICARDA's wheat breeding program has led to the identification of novel source of resistance genes for drought tolerance, heat tolerance and yellow rust resistance (Tadesse *et al.* in press). Molecular screening and rigorous field screening of spring bread wheat genotypes at Njoro, Kenya and at Debrezeit, Ethiopia has led to the identification of Ug99 resistant, widely adapted, and high yielding genotypes. These genotypes have been distributed to the Central, West Asia and North Africa (CWANA) national agricultural research systems (NARS) through ICARDA's International Nursery system. Recently, three Ug99 resistant bread wheat varieties have been released in Ethiopia from such program.

The wheat breeding program at ICARDA also uses physiological and molecular screening techniques in order to increase rates of genetic gains through (a) strategic trait-crossing to combine complementary traits in a progeny, (b) high–throughput phenotyping to enrich desirable alleles in intermediate generations and (c) exploration of genetic resources to broaden the genetic base for hybridization (Reynolds and Tuberose 2008). In addition, precision phenotyping plays a crucial role in gene discovery, and understanding the complex interactions among genes, genetic background and environment (Reynolds and Tuberose 2008). The advent of ever cheaper and more abundant molecular markers make it prudent to accumulate knowledge about the genetics of yield, yield components and physiological traits for application in molecular breeding. Heat and drought adaptive QTL in a wheat population resulting from the cross Seri/Babax designed to minimize confounding agronomic traits have been identified (Lopez *et al.* 2012). The same population was grown across a wide range of environments where heat and drought stress are naturally experienced including environments in Mexico, in the CWANA and South Asia regions. Important genomic regions were identified in chromosome 4A contributing to yield, plant height, canopy temperature and early ground cover in several environments. Moreover, in warm environments, regions were identified in chromosome 5A for yield, 4B for TKW, 6B for days to heading and to maturity and 4A for canopy temperature. These results indicated the importance of the former traits to heat adaptation and the specificity of genomic regions in chromosomes 4B, 5A, and 6B for heat adaptation.

In addition to gene identification and mapping, the wheat breeding program at ICARDA implements marker assisted selection using recommended diagnostic markers. Annually, new parental materials are characterized for disease resistance genes (yellow rust, leaf rust, stem rust, nematodes); insect resistance (Hessian fly and Russian Wheat Aphid), phenological traits such as photoperiodism (*Ppd*), vernalization requirement (*Vrn*); plant height (*Rht*), grain hardness and other genes (Tadesse *et al.* 2012). Diagnostic markers are also used for gene pyramiding in the F_2, F_1top, and BC_1F_1 populations.

ICARDA's durum wheat program has also developed numerous mapping populations as well as an association panel related to drought, biotic stresses and quality (Maccaferri *et al.* 2009, 2011; Habash *et al.* 2009; Haile *et al.* 2012; Mondini *et al.* 2012). Several markers have been identified closely linked to drought tolerance e.g. carbon isotope discrimination. These markers are currently under validation and will be used for marker-assisted selection (MAS). MAS is already being used for quality traits such as yellow pigment, black point, and also biotic stresses such as stem rust.

QTL maps have been developed for several crosses in barley for the identification and location of agronomic traits, especially those related to performance under Syrian dryland conditions. The crosses include Arta/*H.spontaneum* 41-1 (Baum *et al.* 2003; Guo *et al.* 2008; Grando *et al.* 2005), Tadmor/WI2291, Arta/Keel and others. From these bi-parental mapping populations as well as from association panels (Varshney *et al.* 2010, 2011) as well as candidate genes (Nayak *et al.* 2009; von Korff *et al.* 2009) markers are being derived for marker assisted selection. In barley, markers have been derived for food quality traits and drought tolerance, and are being verified and implemented in the breeding program. Diagnostic markers are routinely being used in the barley breeding program for resistance to scald (3H-*Rrs1*), barley yellow dwarf virus (3H-*yd2* and 6H-*yd3*), cereal cyst nematode (2H-*Ha2* and 5H-*Ha4*), spot form net blotch (7H-*Rpt4*) and powdery mildew (1H-*Mla* and 4H--*Mlo*) and for seasonal growth habit (*Vrn*).

In order to examine how molecular polymorphism in barley landraces, sampled from five different ecogeographical regions of Syria and Jordan, is organized and partitioned, genetic variability at 21 nuclear and 10 chloroplast microsatellite loci were examined (Russell *et al.* 2003). Chloroplast polymorphism was detected, with most variation being ascribed to differences between the five regions (*Fst*= 0.45) and to within sites within each region (*Fst*= 0.44). Moreover, the distribution of chloroplast polymorphism is structured and not distributed randomly across the barley landraces sampled. From a total of 125 landrace accessions (five lines from each of five sites from each of five regions) genotyped with 21 SSRs a total of 244 alleles were detected, of which 38 were common to the five regions sampled. Most nuclear variation was detected within sites. Significant differentiation between sites (*Fst*=0.29) was detected with nuclear simple sequence repeats (SSRs) markers and this partially mirrored polymorphism in the chloroplast genome. Strong statistical associations/interaction was also detected between the chloroplast and nuclear

SSRs, together with non-random association (linkage disequilibrium) of alleles at both linked and unlinked SSR loci. These results are discussed in the context of adaptation of landraces to the extreme environments, the concept of 'adapted gene complexes' and the exploitation of landraces in breeding programs.

The first application of an oligonucleotide pool assay single nucleotide polymorphism (SNP) platform to assess the evolution of barley was done in a portion of the Fertile Crescent, a key region in the development of farming (Russell *et al.* 2012). A large collection of >1000 genetically mapped, genome-wide SNPs was assayed in geographically matched landrace and wild barley accessions (N=448) from Jordan and Syria. Landrace and wild barley categories were clearly genetically differentiated, but a limited degree of secondary contact was evident. Significant chromosome-level differences in diversity between barley types were observed around genes known to be involved in the evolution of cultivars. The region of Jordan and southern Syria, compared with the north of Syria, was supported by SNP data as a more likely domestication origin. Our data provide evidence for hybridization as a possible mechanism for the continued adaptation of landrace barley under cultivation, indicate regions of the genome that may be subject to selection processes, and suggest limited origins for the development of the cultivated crop.

Identifying barley genomic regions influencing the response of yield and its components to water deficits will aid in our understanding of the genetics of drought tolerance and the development of more drought tolerant cultivars (Comadran *et al.* 2007). We assembled a population of 192 genotypes that represented landraces, old, and contemporary cultivars sampling key regions around the Mediterranean basin and the rest of Europe. The population was genotyped with a stratified set of 50 genomic and EST derived molecular markers, 49 of which were Simple Sequence Repeats (SSRs), which revealed an underlying population sub-structure that corresponded closely to the geographic regions in which the genotypes were grown. A more dense whole genome scan was generated by using Diversity Array Technology (DArT*1*) to generate 1130 biallelic markers for the population. The population was grown at two contrasting sites in each of seven Mediterranean countries for harvest 2004 and 2005 and grain yield data collected. Mean yield levels ranged from 0.3 to 6.2 t/ha with highly significant genetic variation in low-yielding environments. Associations of yield with barley genomic regions were then detected by combining the DArT marker data with the yield data in mixed model analyses for the individual trials, followed by multiple regression of yield on markers to identify a multi-locus subset of significant markers/ QTLs. QTLs exhibiting a predefined consistency across environments were detected in bins 4, 6, 6 and 7 on barley chromosomes 3H, 4H, 5H and 7H respectively.

Lakew *et al.* (2012, 2013) investigated associations between markers and drought related traits on a set of 57 advanced barley breeding lines, carrying various levels of introgression from *Hordeum spontaneum* lines 41-1 and 41-5, the best sources of drought tolerance in the ICARDA barley breeding program, using 74 simple sequences repeats (SSR) and 20 single nucleotide polymorphism markers (Lakew *et al.* 2011, 2013). The 57 lines were evaluated for grain yield and drought related traits for three years (2003/04, 2004/05, 2005/06) in nine Mediterranean low rainfall environments. A high level of polymorphism was found with SSR markers, and the mean polymorphism information content and gene diversity values were 0.67 and 0.71, respectively. The number of alleles per locus varied from 2 to 11, with an average of 5.8 alleles per marker. Considering all the 57 lines, the linkage disequilibrium (LD) analysis was significant at a comparison-wise P\0.01 level in nearly 9 % of the SSR marker pairs used and a decay of LD was observed to a value of r2\0.2 at a genetic distance of 40 cM. The association analysis revealed a total of 147 significant marker–trait associations for grain yield and drought related traits. A total of 72 (49 %) marker–trait associations showed favorable effects of the exotic germplasm where the *H. spontaneum* lines contributed to an improvement of the trait under drought stress conditions. The number of significant marker–trait associations per trait were: 12 for growth habit; 2 for growth vigor; 11 for peduncle extrusion; 5 for number of grains per spike; 20 for peduncle length; 16 for days to heading; 20 for plant height; 8 for spike length; 17 for thousand kernel weight; 30 for grain yield; 4 for harvest index and 2 for biological yield. The phenotypic variation explained by individual marker–trait associations ranged from 7.6 % to 36.2 %. The identification of genomic regions associated with grain yield and drought related traits is useful for the genetic improvement of cultivars better adapted to drought stress environments. Thus, the present study is encouraging in identifying significant marker–trait associations through LD based association mapping analysis, which could complement and augment previous quantitative trait loci information for the potential use of Marker Assisted Selection for drought.

ICARDA worked with Frankfurt University to develop SSRs for chickpea. More than 200 SSRs were developed and used to produce the first extended linkage map in chickpea and to assess genetic variation in chickpea collections (Udupa *et al.* 1999; Baum and Udupa 2003). Genetic dissection of pathotype-specific resistance to Ascochyta blight disease in chickpea using microsatellite markers revealed a major locus (*ar1*, mapped on linkage group 2), which confers resistance to pathotype I, and two independent recessive major loci (*ar2a*, mapped on linkage group 2 and *ar2b*, mapped on linkage group 4), with complementary gene action conferring resistance to pathotype II. Marker-assisted selection is currently being used for some traits in chickpea, such as resistance to Ascochyta blight disease. Additionally, a recombinant inbred population of 200 lines has been genotyped with 100 markers and phenotyped across four locations to identify drought tolerance. Multi-environment QTL analyses for drought related traits in chickpea has been done using a recombinant inbred line (RIL) population, comprising 181 lines derived from ILC588 X ILC3279 (Hamwieh *et al.* 2013). This population was evaluated in 10 environments across three locations with different moisture gradients. The results indicated that two RILs (152, 162) showed the best grain yield and drought resistance score under stressed and non-stressed environments. The QTLs analyses detected 93 significant QTLs (LOD ≥ 2.0) across the genome × environment interactions. Four common possible pleiotropic QTLs on LG3 and LG4 were identified as associated with days to flowering, grain yield, days to maturity, harvest index, seed number, pods number and drought resistance score (DRS). The QTL for DRS was detected as a conserved QTL in three late planting environments. The allele from the tolerant parent ILC588 at locus H6C07 explained up to 80% of the yield increase under late planting and dry environments. Concentrating on LG3 and LG4 in molecular breeding programs for drought could speed up improvement for these traits.

In lentil, SSR markers were developed and mapped in a mapping population (Hamwieh *et al.* 2005, 2009). Ten new mapping populations targeting different traits are under development. Markers were earlier identified linked with Fusarium wilt and radiation frost tolerance. SSR markers and mapping populations are also being developed for faba bean. Ongoing research will help scale up use of the technology for other traits.

Molecular markers are also being used to characterize pathogens and pest in the CWANA region. Either AFLP or SSR markers (where available) have been used to characterize populations of Hessian fly (El-Bouhssini *et al.* 2010), Sunn pest (Trissi *et al.* 2013), *Rynchosporium secalis* (scald) (Abang *et al.* 2006), *Pyrenophora teres* f. *teres* (Bouajila *et al*. 2013), *Ascochyta rabiei* (blight) in chickpea (Atik *et al*. 2013), *Fusarium oxysporium* in lentil and chickpea, cereal cyst and other nematodes.

SuperSAGE, an improved version of the serial analysis of gene expression (SAGE) technique, generating genome-wide, high-quality transcription profiles from any eukaryote, has been employed to study gene expression in chickpea roots in response to drought (Molina-Medina *et al.* 2008). A total of 80,238 26 bp tags representing 17,493 unique transcripts (UniTags) from drought-stressed and non-stressed control roots were sequenced. A microarray carrying 3,000 of these 26 bp tags were designed. The study represents the most comprehensive analysis of the drought-response transcriptome of chickpea available to date. This study characterized a series of stress responsive genes of chickpea at transcriptome level which is prerequisite for production of expression markers and microrrays for high throughput germplasm characterization and expression (e)QTL analysis. It also demonstrates that certain transcript isoforms characterizing numerous different metabolic and signal transduction pathways are potential targets for knowledge-based breeding for drought tolerance.

Microarray analysis has been used in barley to monitor changes in gene expression at the transcriptional level in leaves during the reproductive stage under drought conditions (Guo *et al.* 2009). The 22K Affymetrix Barley 1 microarray was used to screen two drought-tolerant barley genotypes, ‘Martin’ and *Hordeum spontaneum* 41-1 (‘HS41-1’), and one drought-sensitive genotype ‘Moroc9-75’. Seventeen genes were expressed exclusively in the two drought-tolerant genotypes under drought stress, and their encoded proteins may play significant roles in enhancing drought tolerance through controlling a number of metabolic and signal transduction pathways. These candidate genes are being mapped into the mapping populations and used for other drought-related experiments to provide new insights on drought-tolerance mechanisms in barley.

Genetic engineering

ICARDA is exploring the possibility of using genetic engineering to improve tolerance to fungal diseases, and resistance to drought and other abiotic stresses (Baum and Madkour 2006). Reliable transformation protocols have been established for chickpea and lentil based on *Agrobaterium*-mediated transformation (Khatib *et al.* 2007). Development of a transformation system for faba bean is underway. A number of constructs are being introduced at ICARDA for biotic and abiotic stress resistance. Tests have confirmed the integration of *BI-GST/GPX*, *DREB1A*, *LeTpx*1, *vst*-1 and *chitinase* genes in the target species, in addition to the plant marker genes *bar* and *npt*II. Advanced generation T3-T5 are available for some of the constructs. Functional tests are being carried out to characterize the transformants such as challenging with Fusarium wilt, *Botrytis cinerea*, growing transgenic plants on PEG media etc. Work on legume transformation was conducted in collaboration with the University of Hannover, and Deutsche Sammlung for Microorganism (DSMZ), Braunschweig, Germany and the Center for Legume Improvement in Mediterranean Environments (CLIMA), Australia.

Conclusion

Development of large numbers of molecular markers, high density genetic maps, and appropriately structured mapping populations and genetic diversity panels have now became routine for many crop species. The ability to simultaneously define gene action and breeding value at hundreds and often thousands of loci distributed relatively uniformly across entire genomes is now possible for many of the dryland crop species. However, the biggest challenge in plant genetic improvement remains identifying those gene combinations that lead to significant genetic improvement for enhancing resilience of major dryland crops to climate change in dry areas. The most effective approach to accelerate such efforts is to better integrate the different research disciplines and activities.

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CleanStar Mozambique: A commercial model for increasing food and energy security by integrating smallholder-based farming, bioprocessing, and retail distribution of food and clean energy products

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Extended abstract

CleanStar Mozambique is a vertically-integrated food, energy and forest protection business with operations in agriculture, agro-processing and retail. The company enables smallholder farmers in central Mozambique to transition from slash and burn subsistence farming to sustainable surplus production by promoting agroforestry, crop rotation and intercropping practices for rainfed cassava, cowpeas, pigeonpeas, sorghum, groundnuts and soybean cultivation. CleanStar's extension staff supplies improved planting material and technical assistance to over 1000 associated smallholder farmers, and guarantees to buy all the surpluses produced using CleanStar's farming model. CleanStar pre-processes and stores these crops at its local procurement centers, and then transports them in bulk to a central bioprocessing plant for conversion into a range of food products and an ethanol-based cooking fuel. CleanStar sells the cooking fuel in daily (1 liter) and weekly (5 liter) quantities along with a safe and efficient ethanol stove --at prices that are competitive with charcoal-- via a network of company shops and street vendor resellers in Maputo.

CleanStar Mozambique was established in 2010 by a consortium of international investors to implement a commercial "proof-of-concept" for this model, before replication on a pan-African scale from 2014. The venture features extensive application of new and adapted technologies, including advanced technologies for gathering and communicating technical and operational data with growers, decentralizing pre-processing and storage, managing quality, and streamlining smallholder procurement logistics. CleanStar's custom-designed bioprocessing plant incorporates enzyme and fermentation technologies that are typically only used in larger-scale, world-class bioprocessing plants. These innovations allow for more efficient energy, water, logistics, and workforce management, and fundamentally strengthen the resilience of the venture by maximizing operating flexibility in a highly unpredictable environment. This paper presents a framework for evaluating the CleanStar Mozambique "proof-of-concept" for techno-economic viability, socio-economic benefits, and lifecycle environmental impacts. It shares preliminary empirical scientific and developmental findings regarding CleanStar's model and extrapolates long-term food security, income generation, forest protection and climate change mitigation impacts.

Plenary Session 6

(Special Session on *Dryland Systems*)

Integrated agricultural production systems for improved food security and livelihoods in dry areas

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Abstract

The CGIAR Research Program (CRP) on Dryland Systems, or "Integrated Agricultural Production Systems for Improved Food Security and Livelihoods in Dry Areas," targets the poor and highly vulnerable populations of the dry areas. It aims to develop technology, policy, and institutional innovations to improve food security and livelihoods using an integrated systems approach. The program will be implemented through 4 strategic research themes which will: 1) Bring together all relevant stakeholders to design, implement, and evaluate research goals and extension; 2) Reduce risk in highly vulnerable dryland areas; 3) Sustainably intensify production in higher potential areas; and 4) Intensively evaluate program outputs to ensure effective outcomes. Gender intervention will play a significant role in the CRP as no development can occur if the views and needs of women are left unaddressed. Project outcomes will vary according to agro-ecological setting. In areas for which reduced vulnerability is a primary need, a 10-20% increase in productivity will be sought over the course of the CRP. In areas in which sustainable intensification has been agreed upon as a primary objective a 20-30% increase in productivity will be sought. These results will be accomplished through adoption rates of at least 20% of each of the Action Sites.

Targeting the poor and vulnerable in the developing world

Dryland systems are found where precipitation tends to be low and erratic, and water supply is usually (but not always) the most limiting factor to agricultural production. They are characterized by persistent water scarcity, frequent drought, high climatic variability, and, especially in developing countries, various forms of land degradation, including desertification and loss of biodiversity. About two-thirds of the land under dryland systems consists of rangeland. Individual farms are typically smallholdings of only a few hectares. As with any agricultural system, dryland systems consist of a combination of plant and animal species and management practices selected by farmers to pursue livelihood goals that are based on several factors, including climate, soils, markets, capital, and tradition. However, risk is especially endemic in dryland systems. The Dryland Systems CRP is therefore about developing approaches that simultaneously mitigate risk and increase productivity to enhance food security and improve livelihoods.

In developing countries, there is little or nothing in the way of safety nets to manage risk in the event of system shocks such as drought, price rise, or pestilence. Livelihood goals of dryland farmers therefore tend more towards food security, stability, and risk avoidance, with profit often as a more secondary goal. Especially for poor small landholders in developing countries, an integrated and diverse approach is important to managing risk or increasing resilience. Dryland farmers (including pastoralists) need to understand and manage the many components of their particular production system, which may include various soils, landscapes and sources of water, and several plant and animal species. Often, they must add value to their products, e.g. through processing or marketing, to form viable businesses. And they must cope with spatial and temporal climatic variability, including complex facets of climate change. Therefore, traditional and improved plant and animal species, indigenous and introduced technologies, access to markets and financial resources, and communication of knowledge are all important parts of the mix. Management focus on any one system component or commodity in isolation from the others is unlikely to significantly improve livelihoods, and indeed may cause resource degradation, compromise food security, or otherwise increase risk.

The overarching challenge for the Dryland Systems CRP is to deliver food security and livelihood benefits to the poor and vulnerable of dryland systems, and especially to marginalized segments of society. As with all CGIAR Research Programs (http://www.cgiar.org/our-research/cgiar-research-programs/), Dryland Systems CRP will contribute to the four system-level outcomes of reduction in rural poverty, increased food security, improved nutrition and health, and sustainable management of natural resources.

Predominance of dryland areas

The dry areas of the developing world occupy about 3 billion hectares, or 41% of the earth‘s land area (Fig. 1), and are home to 2.5 billion people, or more than one-third of its population. About 16% of this population lives in chronic poverty. Dry areas face several demographic challenges, including rapid population growth, high urbanization, youth-skewed age distributions, and the world‘s highest unemployment rate. Dry areas also have limited natural resources and face serious environmental constraints that are likely to worsen as a result of climate change.

Conceptual framework for research

To set research priorities within the Dryland Systems CRP, a conceptual framework for the CRP was developed with stakeholder participation as part of a workshop held in January 2012 (Fig. 2). The framework consists of four **Strategic Research Themes (SRTs)**, each derived from a hypothesis:

1. The use of innovation systems will improve the effectiveness of agricultural research for development in contributing to, defining, and delivering target outcomes to complex dryland systems. It further assumes that innovation systems and partnerships will more effectively drive policy change and technology adoption in these often politically marginalized environments with limited technology access. This hypothesis has led to the establishment of **SRT1**.
2. For a significant proportion of livelihood systems in the most vulnerable and degraded dryland areas, increased food security, reduced risk, and improved resilience are fundamentally achievable through technical and institutional innovations, and can lead to more secure and improved livelihoods without land degradation and other forms of unsustainability. Those areas where this is not possible would be better targeted with alternative land-use and livelihood systems. This overarching hypothesis will be tested in **SRT2**.

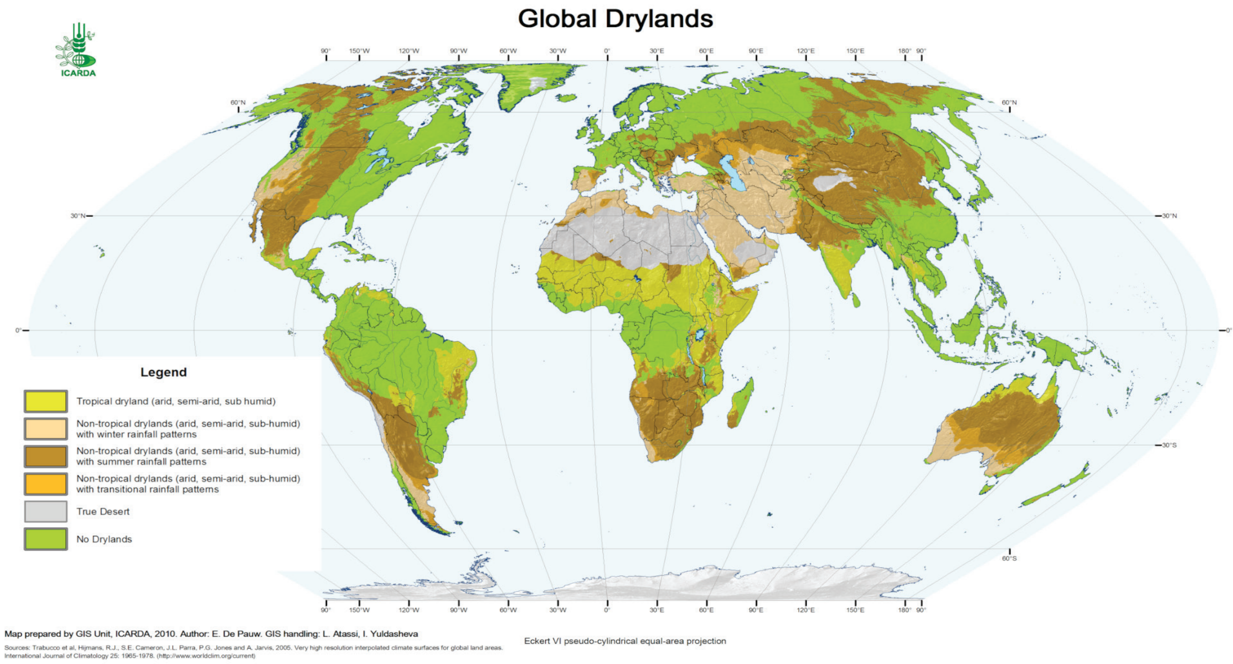


Figure 1: Global drylands map.

3. Certain parts of the dry areas have potential to significantly contribute to economic growth. The overarching assumption is that substantial and sustainable production increases can be realized through innovations that will lead to intensification and diversification of production systems and the development of the necessary value chains. The extent to which this assumption holds will be studied in **SRT3**.
4. The complex nature of the pathway to generating outputs and outcomes in Dryland Systems can be captured only with the help of biophysical and socioeconomic models that function at different scales. These can provide the necessary insights to inform the innovation system and to generate the information, communication, and knowledge-transfer needs for up- and out-scaling of the innovations and for measuring their potential impact. The system analysis platform needed to test this assumption and verify models with real-time information will be elaborated in **SRT4**.

Steps in the impact pathway

The four SRTs constitute essential steps or components of the impact pathway (Fig. 3), which describes how the CRP intends to achieve its targeted impacts for improving food security and livelihoods in dryland systems**. SRT1** recognizes growing evidence that innovation systems that actively involve relevant stakeholders as part of the development process offer rapid feed-forward, feedback, and scaling-up mechanisms needed to address development in agricultural systems with marginal resources and complex scale dependencies. Innovation platforms will be applied to address complex problems and constraints in the two broad categories of dryland systems, i.e. those with the deepest endemic poverty and most-vulnerable people (**SRT2**), and those with the greatest potential to contribute to food security and poverty reduction (**SRT3**)

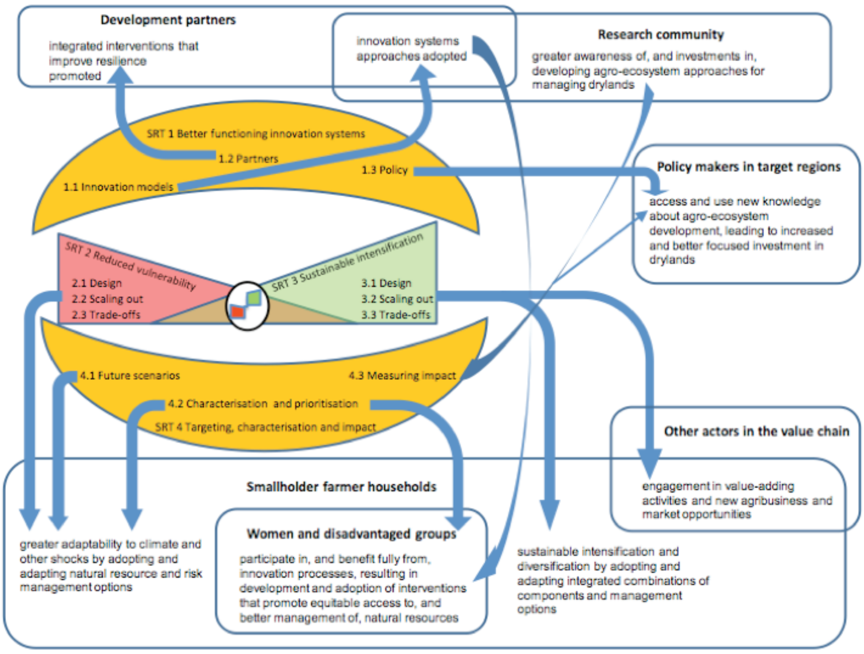


Figure 2: Conceptual framework of Dryland Systems CRP.

(Fig. 4). Capturing the process with a view towards knowledge synthesis and out-scaling, either within or between regions, is at the heart of **SRT4**, which will require the development and use of monitoring and evaluation tools, and various biophysical and socioeconomic models that function at different scales. SRT4 is meant to provide the insights needed to inform the innovation system and generate information and facilitate communication and knowledge transfer for continued learning and up- and out-scaling.

Within each SRT, problems and their underlying constraints are identified and addressed through a set of research hypotheses tailored to the two categories of dryland systems in different regions. Hypothesis-driven research is designed to produce research **outputs,** which will be determined through innovation platforms and engagement with policy makers, produced through individual research-related **activities. Outputs** will contribute to the delivery of targeted development **outcomes,** which in turn address identified problems and constraints. Many impact pathways distinguish between research and development outcomes. This distinction is blurred in Dryland Systems CRP, however, because of the role of Innovation Platforms as both designers and adopters of the outputs. A brief summary of the four SRTs' program-level outputs is given in Table 1.

Categorizing dryland production systems and identifying research locations

As depicted in Fig. 2, Dryland Systems CRP will operate in two notional types of production systems in each of five regions, with different priorities in each type: In SRT2 (marginal, with high vulnerability) systems, the goals are to increase productivity by 10–20% and reduce vulnerability. In SRT3 (higher production potential, with capacity for sustainable intensification), the goal is to sustainably increase productivity by 20–30%. These goals are based on the overall

Table 1: Strategic research themes and associated outputs for the Dryland Systems CRP

Strategic research theme	Output
1. Approaches and models for strengthening innovation systems, building stakeholder innovation capacity, and linking knowledge to policy action	Approaches and models for strengthening innovation systems, building stakeholder innovation capacity, and linking knowledge to policy action
	Enhanced capacity for innovation and effective participation in collaborative processes for international agricultural research for development
	Strategies for effectively linking research to policy action in a dryland context
2. Reducing vulnerability and managing risk through increased resilience	Combinations of institutional, biophysical, and management options for reducing vulnerability designed and developed
	Options for reducing vulnerability and mitigating risk scaled up and out within regions
	Trade-offs among options for reducing vulnerability and mitigating risk analyzed (within regions). Knowledge-based systems developed for customizing options to sites and circumstances
3. Sustainable intensification for more productive, profitable, and diversified dryland agriculture with well-established linkages to markets	Sustainable intensification options designed and developed
	Sustainable intensification options scaled out
	Trade-offs among sustainable intensification and diversification options analyzed (within regions). Knowledge-based systems developed for customizing options to sites and circumstances
4. Measuring impacts and cross-regional synthesis	Future scenarios and priority setting
	Livelihood and ecosystem characterization. Across-region synthesis of lessons learnt from SRTs 2 and 3
	Program impacts measured

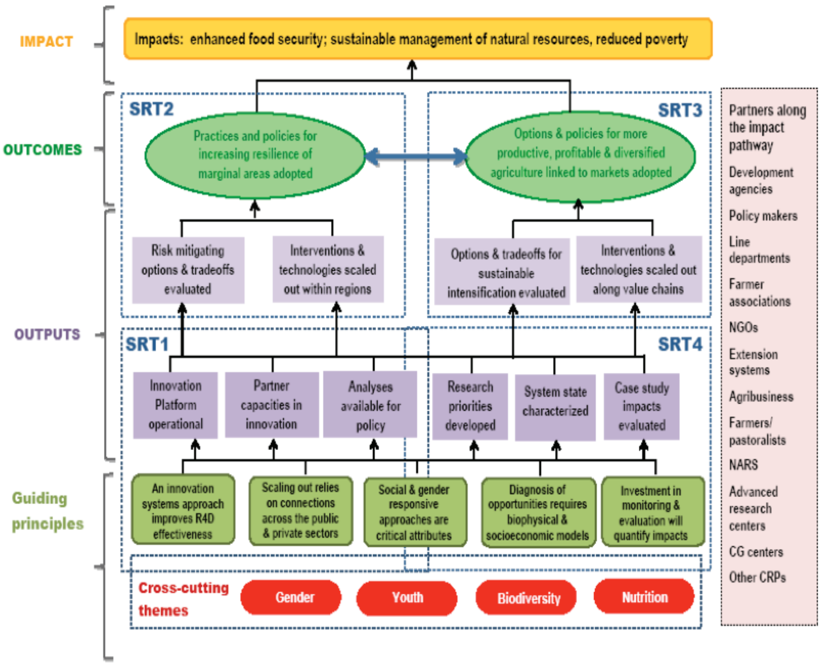


Figure 3: CRP1.1 Program impact pathway.

perception that in the SRT2-type systems, which are largely dry, marginal, resource-poor areas with poor institutions and poor market connectedness, there are opportunities to avoid resource degradation and reduce vulnerability to system shocks and climate change. On the other hand, SRT3-type systems are broadly less marginal areas that tend to have better institutional support and access to markets, and there are more opportunities to sustainably intensify production. A more detailed description of the two notional categories follows.

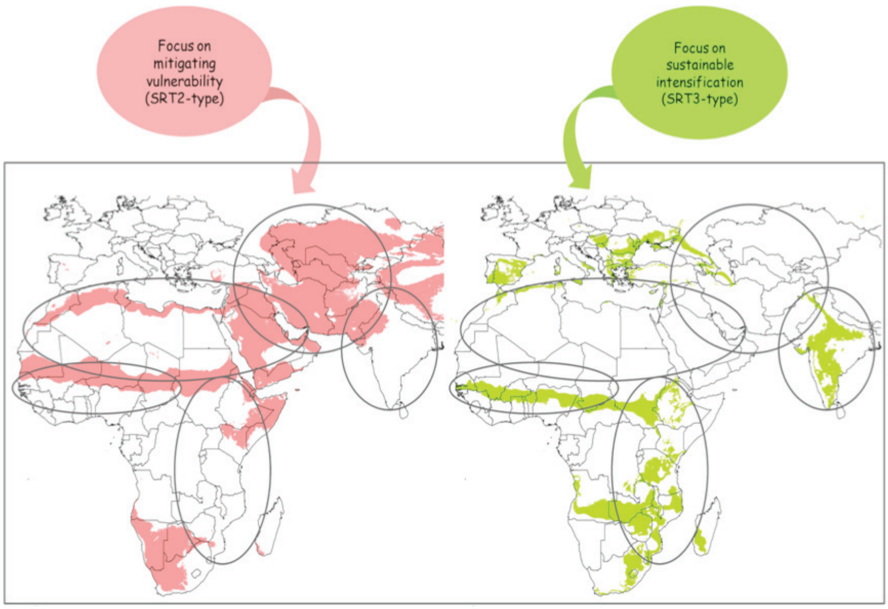


Figure 4: Categories of dryland systems.

Strategic Research Theme 2: Reducing vulnerability and managing risk

In marginal dryland agricultural systems, which typically are characterized by severe water scarcity and fragile lands, productivity per se is not the primary driver of agroecosystem management. Often yield stability has priority over high yield, productivity per unit of the most limiting factor (water, labor, or time) has priority over productivity per unit of land, and input efficiency has priority over input response. Furthermore, system shocks, often influenced by climate variability, resulting in a single failed crop or grazing season, a livestock disease epidemic, or a shift in market structure can have a catastrophic impact on vulnerable communities. Building adaptive capacity is therefore an integral part of reducing poverty and ensuring food security in these areas.

Getting the mix right in terms of alleviating poverty, enhancing food security, and ensuring environmental sustainability is crucial under these conditions. This requires understanding the roles that each of these elements play in the livelihoods of rural communities and farming systems and how these roles change under different contexts and over time. It is also important to realize that once communities fall into the poverty trap, immediate food-security concerns may override long-term sustainability considerations, and a vicious cycle ensues that deepens poverty and leads to further resource degradation. Reduced vulnerability and increased resilience are therefore desired research and development outcomes.

Ultimate impacts will include significant reduction in poverty and, more particularly, reduction of vulnerability of the resource-poor and the natural resource base on which they depend.

Strategic Research Theme 3: Sustainable intensification

Research under this theme will target dryland systems with the greatest potential for impact on poverty in the short to medium term. Market oriented systems offer possibilities for intensification of existing farming systems through more efficient use of natural resources combined with production options and opportunities along one or more value chains. Sustainable intensification aims at increasing input use to increase output, based on principles of sustainability. Sustainable intensification opens possibilities for adopting higher-value crops, improved livestock, and value-adding activities that increase profitability of the farming systems.

Incentives and profit are the major drivers for technology adoption and intensification of farming systems. Farmers are much more likely to invest in inputs and technologies for increased production where there is a profit incentive.

Ultimate impacts include reducing farmers' climate-related risks; mitigating the future impacts of intensification on climate change, and developing resource technologies that reduce risk but could also increase productivity under more favorable conditions.

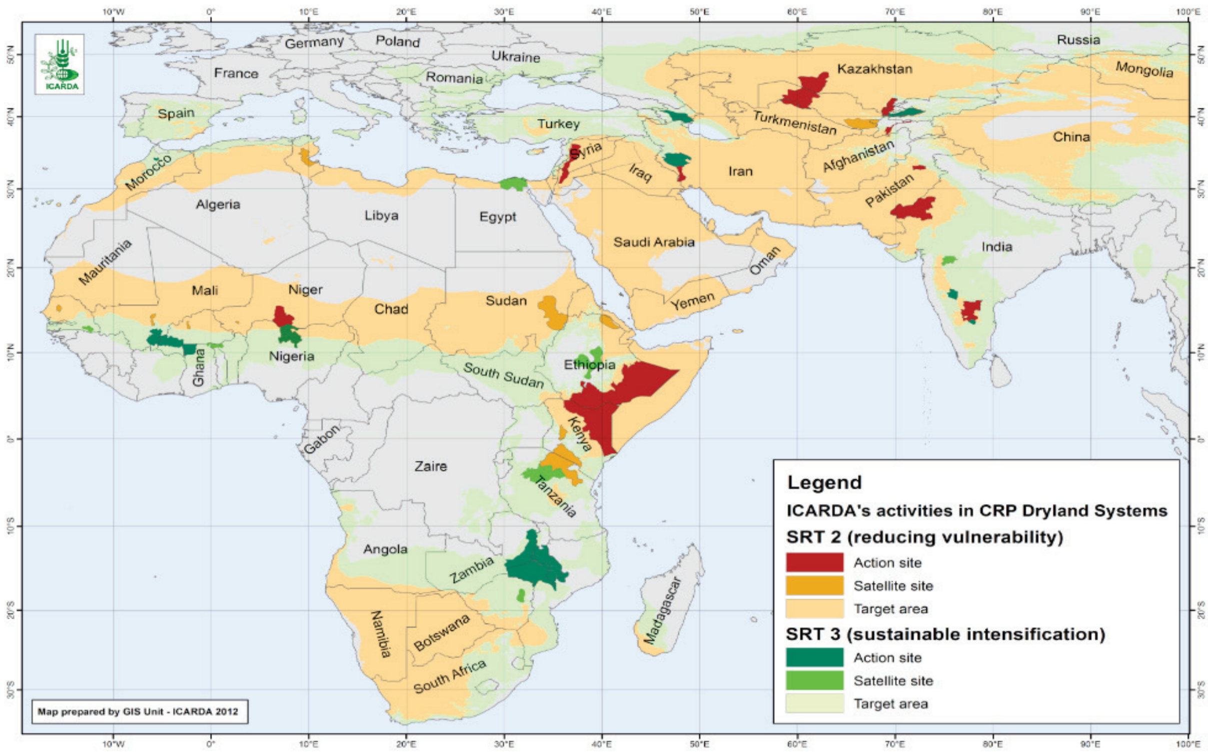
Table 2: Criteria for target area selection

Criteria	Limits for SRT 2	Limits for SRT 3
Length of growing period	<90 days	90-180 days
Distribution of poverty		
Hunger and malnutrition (food security, no of people, % of people)		
Aridity Index	0.03 to 0.35	0.35-0.65
Environmental risk (Rainfall variability, access to irrigation,	CV>15%	CV<15%
Land degradation (soil salinity, soil erosion)	High	Low-medium
Market access	Travel time >2 hrs	Travel time <2 hrs
Population density		

For each region in which the CRP will work, SRT2 and SRT3 Target Areas were identified using the criteria shown in Table 2. Subsequently, Action Sites, where the bulk of research will be carried out, and Satellite Sites, where unique research and outscaling opportunities exist, were chosen based on the criteria shown in Table 3. Target Areas and Action and Satellite Sites for all five regions are shown in Fig. 5.

Table 3: Criteria used for choosing potential action and satellite sites in target areas

Target Area	Potential Action Site 1	Potential Satellite Site 1	Potential Satellite Site 2
Country			
Geographical location			
Accessibility			
Potential for hypothesis testing			
Representativeness			
Potential for out-scaling (impact)			
Potential to attract funds			
Potential to interact with CRPs			



.**Figure 5:** Action and satellite sites for two types of dryland production systems

Impact goals

Dryland Systems CRP has been designed to formulate research, extension and policy solutions on a more holistic agro-ecosystem level, thereby ultimately allowing it to address countries' specific needs over longer time horizons and to provide policy makers with practical policy options to respond to the realities of chronic poverty and food insecurity, including nutritional

Table 4: Preliminary projections of impact of dryland systems on livelihoods and reversing land degradation

Region	Lives Improved (millions)	Land Degradation Mitigated (km^2)
SubSaharan Africa	20.0	600,000
Central Asia	0.5	940
South Asia	65.0	465,000
North Africa and West Asia	1.1	18,600
Total Impact in Dryland Areas	86.6	1,084,540

deficits. Research that examines all combinations of crop, livestock, tree, fish, natural resource management, policy, and income will be provided by the systems approach being utilized by Dryland Systems CRP.

Preliminary projections of the Dryland Systems CRP on improving livelihoods and reducing land degradation are shown in Table 4, assuming adoption rates within Action sites of 20%.

Commonalities among five regions

Even though Dryland Systems CRP will be implemented within five highly variable regions, each with its own biophysical and socioeconomic specificities, the research program will nonetheless strive to maintain global research themes based on commonalities among the regions. In 2012, five regional inception workshops were held with literally hundreds of stakeholder partners. Each workshop produced a written report (https://www.dropbox.com/sh/re7agtx08d9onmq/awdNY3jCYN) which included descriptions of production constraints, research and development outcomes, and research hypotheses. Commonalities among the five regions are summarized below.

Common problems among the five target regions

- The unsustainable management of natural resources given high rainfall variability and moisture stress
- High levels of rural poverty
- Resource stress as a result of demographic change
- Limited understanding of the degree and scope of vulnerability among dryland populations
- Lack of communication between national research and development programs, NGOs and CGIAR Centers
- Inadequate policy to promote technology for agricultural and pastoral rehabilitation within government
- A policy environment that does not encourage adoption of new technology and limits market access

- The marginalization of women, youth, and other groups.
- Poor soil- and water-management practices that cause land and water degradation
- Development goals are not agreed upon in a participatory, multi-stakeholder environment
- Decreasing or insufficient biomass and system productivity
- Declining or insufficient agrobiodiversity
- Poor access to information regarding new technologies or techniques
- Decreasing landholding size
- Inaccessibility of markets and financial resources
- The increasing vulnerability of rural farming communities as a result of resource, knowledge, and institutional changes
- The inefficient utilization of water resources in dryland environments
- Degraded soils constrain productivity and sustainability
- Climate change is causing rapid degradation of natural resources
- Increasing competition for scarce biomass
- A lack of investment in the production of livestock-related products

Widely shared outcomes between the five target regions

- A widely agreed upon framework to define and measure vulnerability for the purpose of informing policy and programming
- Farmer attainment of higher plant and livestock productivity and profitability
- Increased food security, including better nutrition
- Improved rural employment
- Greater biomass availability for animal and cropping systems
- Improved access to and adoption of appropriate technology and technical advice by smallholder farmers
- Better access to markets and financial services by smallholder farmers
- High-value product markets made accessible to smallholder farmers
- More-effective buffering and system resilience to reduce vulnerability to system shocks and climate change
- Higher levels of empowerment for youth and women in community decision-making
- Stronger institutions to serve the rural poor and greater government awareness about system and livelihood interdependencies, leading to more-effective policy changes and institutional innovations
- Broad stakeholder participation in the research and development cycle through innovation platforms
- Higher levels of biodiversity and lower levels of land degradation facilitated through better management of soil, water, and genetic resources
- Farmers are equipped to manage their natural resources in a more sustainable way
- Improved options for mixed production systems are communicated to smallholder farmers.
- Trade-off analyses to establish the optimal mix of land use/land cover and cropping systems
- Dryland Systems CRP to inform other CRPs, and vice versa
- Better understanding of system characteristics, opportunities, and constraints
- Effective communication of CRP findings to all stakeholders
- Postharvest and processing technologies have been improved and communicated and value-adding options increased

Widely shared hypotheses between the five target regions

Commonalities in the research hypotheses are particularly crucial to giving a sense of how the overall CRP comes together to solve a common set of research problems despite implementing that research in a number of locations. Common foci included water management, soil improvement, value chains, biodiversity, technology transfer, ecosystem resilience, social networking, institutional reform, access to physical and financial markets, gender, and youth.

Partnerships

Successful partnership has been built into the CRP as a guiding principle since its inception because of the belief that successful dryland production systems evolve through the right mix of partnerships, technologies, and appropriate policies. This is appropriate and even necessary because Dryland System CRP research outcomes cannot go to scale or achieve impact without partner support and buy-in. Partners are involved all along the Impact Pathway (Fig. 3) and includes Development agencies, Policy makers, Farmers associations, NGOs, Extension systems, NARS, Advanced Research Centers, etc. Partnership is explicitly part of the conceptual framework (Fig. 2) and the central point of SRT1, as well as outputs of SRT2 and SRT3 on scaling out (Table 1). Partners were involved in the participatory selection of Action Sites, the extensive groundwork conducted to characterize SRT2 and SRT3 Target Areas, and in the research prioritization exercises that took place during the five regional workshops. Partners are also involved in governance of the CRP, as they serve on the Steering Committee, the Independent Science Advisory Committee, the Regional Management Committees, the Regional Stakeholder Advisory Committees, and the Regional Science Advisory Committee.(Governance structures are described in section 10 of the Dryland Systems CRP proposal, available at http://www.icarda.org/dryland_systems/teaser).

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Integrated agricultural production systems for improved food security and livelihoods in North Africa and West Asia

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Extended abstract

The Dryland Systems CGIAR Research Program (DS-CRP) targeting the poor and highly vulnerable populations of the dry areas aims to develop technology, policy and institutional innovations to improve livelihoods, using an integrated systems approach. In North Africa and West Asia (NAWA), DS-CRP focuses on two types of dryland systems: (i) those with the driest climates and the deepest endemic poverty, often associated with severe natural resource degradation and environmental variability (vulnerable agro-ecologies), and (ii) those with the greatest potential for intensification and possibility to impact on food security and poverty (favorable agro-ecologies).

Research for development sites are identified in each of these agroecologies, based on selected biophysical and socioeconomic criteria. For vulnerable agro-ecologies, the transect spanning the region of Tafila in Jordan through Salamiya area in Syria together with a satellite site in Tunisia (transect Béni Khédache-Sidi Bouzid) have been selected. Rural livelihoods in these agro-ecologies are mainly based on production systems in which small ruminants represent the principal economic output encompassing nomadic or semi-nomadic rangeland-based (pastoral system) to mixed crop-livestock smallholder systems (agropastoral system).

For favorable agro-ecologies, the region of Meknes-Saies in Morocco and two satellite sites (Nile Delta in Egypt and Karkheh River Basin in Iran) have been selected. The cereal-based mixed rainfed production system is predominant within the favorable agro-ecologies and is suitable to sustainable intensification for more productive, profitable and diversified dryland agriculture while irrigation-based agriculture is predominant in the Nile Delta. DS-CRP will build upon the previous research and development successes and failures over the past few decades, aiming at prioritizing key agricultural systems for impact.

The approach will identify key researchable issues within specific target agro-ecosystems, develop more resilient agricultural systems to manage risk and production variability, promote conservation and sustainable use of dryland agrobiodiversity and natural resources, improve the productivity and profitability of agricultural systems through sustainable intensification, diversification, value-added products and market linkages, and develop new partnership models. Partnerships will be built within strategic and cluster innovation platforms comprising farming communities, national research and extension systems, policy makers, international and regional organizations, advanced research institutes, civil society and non-governmental organizations, the private sector, and development agencies.

Drivers and major changes in agricultural production systems in drylands of South Asia: assessing implications for key environmental indicators and research needs

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Abstract

The South Asian dryland (arid and semi-arid) ecosystem has been exhibiting considerable agricultural production system changes. There is scientific consensus that this nature of agricultural production system enables it to capture market, technologies and environmental opportunities. Pressing concerns are, however, adverse environmental trade-offs that these changes are experiencing and therefore the challenges toward a resilient agricultural production system. This is particularly important as arid and semi-arid ecosystems are resources constrained and thus more vulnerable: for example to climate change. To stimulate and revive a debate in agricultural research and policy circles, this paper demonstrates the magnitude of major changes, their drivers and environmental implications in context to agricultural production systems in dryland areas in South Asia. As an example we selected districts representing different dryland agricultural production systems in western Rajasthan, Andhra Pradesh and Karnataka states of India. Taking crop, livestock and trees as major enterprises, we characterized agricultural production systems of the sample districts. Key operational resources, demographic and external agents were illustrated as examples of drivers of changes. Major emphasis was given to material and environment related livelihood outcomes and their dynamic as agricultural production system evolves over time. Despite a remarkable improvement in material outcomes of agricultural production (> 100% increase in cereal grain yields taking 1966 as a base year), the long term environmental dimension tends to be compromised by short term needs: as demonstrated by perpetual soil nutrient stock mining, ground water depletion and instability of cereal grain yields (28-110% CV). Based on these empirical evidence, we debate as to where a system research should focus and what policy circles need to do to address emerging problems and contribute to advances toward a sustainable agricultural production systems in dryland.

1. Introduction

Globally dryland (arid and semi-arid) ecosystem occupies more than 3 billion hectares and is home to 2.5 billion people: the size equivalent to 41% of the earth’s land area and more than one-third of its population (ICARDA 2010). In view of their extent (area) and current intensive use, dryland ecosystems and their associated agricultural production systems in South Asia are of great importance. For example, in India alone, it contributes about 40% of the total food grain production and supports two third of livestock population (Wani *et al.* 2009; CRIDA 2011). One of the growing concerns is, however, that the continuous increases in human population and concomitant demand for livestock and crop products will exert additional pressure to already resources poor and overstretched dryland ecosystem.

The dryland ecosystems are also commended for encompassing several globally important centres of origin and diversity of plant and animal species (Mortimore *et al.* 2009). Dryland in South Asia has large productivity gaps, where relatively quick wins would be possible to meet the livelihood outcomes with minimum adverse environmental consequences.

Efforts to close these yield gaps go back to mid-1960: the time of green revolution (Singh 2000). In some areas there were achievements, but with various environmental consequences (Singh 2000); while in major part of the dryland these potentials are not yet crafted. Here we argue that a systematic evaluation of post-intensification adverse environmental consequences and understanding impeding factors to close yield gaps will help to focus future agricultural production system researches in dryland.

One of the major reasons why research has not delivered more in this regard is that it has been conducted on single components of an agro-ecosystem, while farmers and communities operate in complex systems, with high levels of integration of many components (White *et al.* 1996). For example, commonly recognized yield gaps are only of a single component and hardly include gaps related to synergies and complementarities of system components under the 'right mix'. Changing behaviour of agricultural production system, in response to increasingly diverse exogenous and endogenous factors acting on and interacting with system components (White *et al.* 1996), is also less comprehended and therefore pertinent policy and technical measure to straighten its trajectory, in a way to meet features of sustainable agricultural production, is hardly put into practices (Ison *et al.* 1996).

The overarching objectives, here, were to stimulate the debate in agricultural research and policy circles by highlighting key indicators: as to how the current agricultural production systems structured and functions and how they are evolving and what this implies for environmental sustainability and therefore pertinent research and policy options.

2. Approaches

2.1. Study areas and data sources

Study areas were chosen based on vulnerability maps (NRA/CRIDA 2012), available geospatial information (rainfall, population, soil etc.), and expert opinion. The most vulnerable dryland districts in India include parts of Rajasthan. Therefore here three districts representing the major farming systems in arid ecosystem, including the small ruminants based crop-livestock in Barmer and Jaisalmer and millet based crop-livestock system in Jodhpur, were selected. As a cluster representing dryland systems in semi-arid ecosystems in peninsular India, systems including cereals based crop-livestock system in Bijapur (Karnataka) and ground nut based crop-livestock system in Anantapur and pulses based crop-livestock system in Kurnool districts (Andhra Pradesh), were identified.

Multiple years' district level census data on livestock and crop production, farm size and number of holdings, land use and population were mainly used. Additional data on key environmental indicators were acquired from district contingency plans. Data on trends of Land Use Land Cover Changes (LULCC) were acquired from remote sensing (2000-2010). Expert opinion and discussions with farmers in these districts helped to triangulate information from the different sources mentioned above (Haileslassie and Craufurd, in press).

2.2. Perceptions of agricultural systems and adopted analytical framework

2.2.1. Perception of agricultural production system

Agricultural system was perceived as an assemblage of livestock, tree and crop components which are united by different degrees of integration and interaction (depending on whether the comparative advantage is crop or livestock based system) and which operates within a prescribed 'open-boundary' to achieve specified agricultural objectives (Jodha 1986; FAO 1997). Agricultural production systems is also viewed as a fundamentally dynamic process influenced by endogenous and exogenous agents and being dependent on the passage of time, ex-ante, and their outcomes are uncertain (White *et al.* 1996; Ison *et al*. 1997).

Mixed crop-livestock production systems are major production systems in these areas (Jodha 1986). But the comparative advantage of crop over livestock and *vice versa* is dependent on prevailing biophysical settings. For example system in western Rajasthan are mainly livestock based, while in Anantapur, Kurnool and Bijapur crop production plays a major role.

But generally, in the study areas, drawing a boundary line among the different agricultural production systems and their components can be argued as scale dependent. For a large-scale study, which customarily does not take human decision into account and considers agricultural production systems as a 'black-box', such distinction can be possible. At lower scale, however, where we are most often interested in within and between systems interactions and target interventions, this is a generalization. At this level or scale system boundaries can be drawn that are largely independent of scale. However at lower scale (e.g. community and farm), where we most often are interested in interventions, within and between systems interactions of system components are much more important and cannot be ignored. For example, a farm located in one of the livestock based systems in Jaisalmer villages, having access to ground water or be able to harvest rain water, can maximize its income through integration of crop and livestock. In another scenario a farmer on farm in the same village having no access to these resources may be compelled to depend on livestock management [e.g. common property resources (Jodha 1986)] and off farm labour. As such, agricultural landscapes in the study areas are understood as mosaics of smaller interacting systems (Haileslassie *et al.* 2011).

2.2.2. Analytical framework

For a consistent flow of information, analytical framework depicted on Figure 1 was developed. It proposes interrelated focus areas (structure, enabling environment, system changes, system functions and feedback) in analysing agricultural system. In line with this, first we characterize how the current agricultural production systems, in the study areas, are structured by showing key system components and their major interactions (e.g. Haileslassie and Craufurd, in press). Secondly we discuss the dynamic of key operational/enabling resources taking land holding and LULCC as an example and demonstrate how this influences the trajectories of agricultural system intensification and what it implies for agricultural research. In fact, the impacts of operational resources on agricultural production systems are not liner: there are interactions with exogenous forcing agents such as climate and demographic factors. Examples of these interactions are also highlighted.

Changes in agricultural production systems, in turn, influence the diversity and landscape of livelihood outcomes and agricultural production systems sustainability. Then, thirdly, key indicators of sustainability [e.g. stability and trends of material outputs and environmental health (e.g. soil nutrient stock and water)] were considered to illustrate whether the enduring intensification trajectories are sustainable or not and where agricultural system research should focus to meet the features of sustainable agricultural production

3. Structure of agricultural production systems

3.1. Agricultural production systems in arid eco-systems of West Rajasthan

Crop or livestock based mixed crop-livestock agricultural production systems are major source of livelihood in the study areas. Jodha (1986) described the agricultural systems in western Rajasthan as crop and livestock based and emphasized the comparative advantage livestock farming enjoys over crop farming. Census data and discussion with farmers indicated that small ruminants [sheep (*Ovis aries*), goat (*Capra hircus*)] based crop-livestock production system is the main traditional system in the western Rajasthan (e.g. Jaisalmer and Barmer). Distinct features of this system include low (~<250mm) and erratic rainfall, and herd management that involves seasonal or permanent mobility within and between districts in search of feed and market. Here along the West-East rainfall gradient, crop [pearl millet (*Pennisetum glaucum (L.) R. Br*. and mustard (*Brassica juncea (L.)*] based large ruminant [cattle (*Bos indicus* and *(Bos taurus Taurus)*, buffalo (*Bubalus bubalis*)] production systems are also common. Traditionally trees on permanent pasture lands in these systems are major components of system structure and sources of browse for small ruminants; but their role is increasingly declining due to major conversion of range lands to crop land (Jodha 1986).

One of the major defining factors of the structure for agricultural production systems in *small ruminants based crop-livestock* (in Barmer and Jaisalmer) and *millet base crop-livestock system* (in Jodhpur) is availability of sufficient water. For example with increasing extraction of ground water there is a tendency for change in the traditional livestock herd composition. Experts also ascribe this change to increasing local and global demand for livestock products. District level census data over the last decade shows an increase in total livestock population. Buffalo became an important herd constituent along West-East rainfall gradient while a tendency to shift in composition of small ruminants was observed for the drier, more western part *(i.e. small ruminants based crop-livestock systems)*. An important research issue here could be to understand as to how existing feed resources complement these evolving interests in livestock enterprises.

3.2. Agricultural production systems in semi-arid ecosystems of peninsular India

The semi-arid ecosystems are dominated by *groundnut based crop-livestock* (in Anatapur), *pulses based crop-livestock* (in Kurnool) and *cereals based crop-livestock* agricultural production systems (in Bijapur). These three systems have one common feature: crop production plays important economic role compared to livestock and >75% is rainfed agriculture. In response to divergent biophysical factors (e.g. soil and climate), the major structural difference among the production systems lies in cropping season, crop types and their combinations. The cropping season in *groundnut based crop-livestock* (Alfisols ~78% of the district area) systems of Anantapur is predominantly Kharif (June to October, rainy season) based and is particularly groundnut (*Arachis hypogaea (L.*) dominated. It is usually intercropped with pigeon pea (*Cajanus cajan*) or sunflower (*Helianthus annuus (*L.). In addition to pigeon pea and groundnut on its Alfisol areas the *pulses based crop-livestock* systems in Kurnool district produces Rabi (post rainy season, November to April) chickpea *(Cicer arietinum (L.)* on is its black soil (Vertisol) areas.

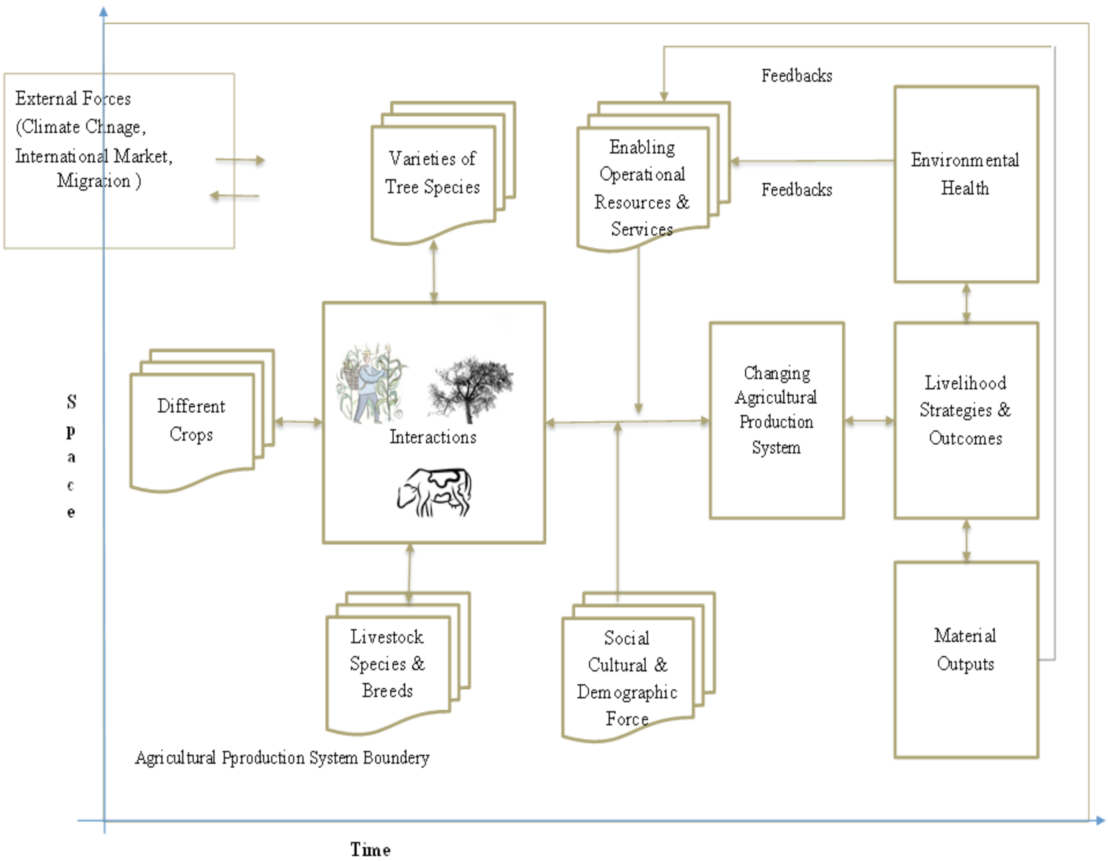


Figure 1: A simplified analytical framework illustrating agricultural system components driving factors, livelihood outcomes and feedbacks: synthesized from FAO (1997) and Rufino et al. (2006).

Depending on soil depth, cropping seasons of the *cereal based crop-livestock* systems in Bijapur can be Kharif, Rabi or both (extended Kharif). The major field crops cultivated in the Kharif include pigeon pea, sunflower and ragi (*Eleusine coracana (L.*). Sorghum [(*Sorghum_bicolor* (L.) *Moench*.)] and chickpea are major Rabi season crops. Both small and large ruminants are integrated into crop production systems in all production systems of the semi-arid ecosystems: i.e. the crop provide major feed sources while livestock recycle nutrients and provide traction services for crop production. The degree of integration varies among systems and depends on the level of intensification.

Between 1996 and 2007 there was a sharp increase in the total livestock population and in terms of livestock head, small ruminants became important component of the herd (e.g. *groundnut based crop-livestock* in Anatapur). Arguably, the market driver - demand for milk - is the same for the two major system clusters (arid and semi-arid) and which is why buffaloes have increased relative to cattle (1966-2007). The overall change in structure of the system from the livestock number perspective contrasts with feed supply which farmers state as a major constraint. With an increasing decline in area and quality of grazing land, crop residues became an important feed ingredient. On the one hand, livestock compete with other biomass uses and users (e.g. conservation agriculture) but on the other hand such crop-livestock interactions are commended for their notable increases in resource use efficiencies (e.g. Haileslassie *et al.* 2012). A key research issue here is identifying an optimum mix of system components over spatial and temporal scales and investigating mechanisms to catch market opportunities with minimum risks to the environment.

4. Enabling resources and trajectories of system changes

4.1. Interplay of demography and operational resources: what for a system change?

Agricultural land is an important input for function of an agricultural production system and from society's point of view supply of land is perfectly inelastic, i.e. fixed in quantity. But from an individual's point of view, its supply is relatively elastic. Alauddin and Quiggin (2008) and Nirula and Thapa (2005) suggest that the interplay among demographic factors (population growth, law of inheritance, land reform measures, rural indebtedness) and land resources is one of the major causes of changes in agricultural production system function. However empirical evidence demonstrating the major determinants among these factors is not available. Therefore, population growth is invariably referred as the major driver of changes of land holding size (e.g. Singh 2000).

Figure 2(A-F) illustrates examples of trends in number of operational land holdings (by holding size) across years in the study areas. Apparently, for the observation period, there was a remarkable increase in the total number of holdings in *groundnut based crop-livestock* system in Anantapur and the *cereals based crop-livestock* system in Bijapur. Similar trend was observed for holdings under marginal (<1 ha), small (1-2 ha) and semi-medium (2-4 ha) farms. Contrastingly, the number of holding size for medium (4-10 ha) and large (>10 ha) farms dropped. Although weak, the *millet based crop-livestock* system in Jodhpur and *small ruminants based crop-livestock* system in Jaisalmer showed similar trends. Perhaps the differences between the arid and semi-arid ecosystems largely depend on the areas of alternative land resources such as the availability or access to more common property resources (e.g. *small ruminants based crop-livestock*) and also to differences in the minimum areas of a holding below which a reasonable economic return is not possible.

As expected, land holding sizes reflect these changes in land holding number with smaller holding and few larger holdings (Fig. 3A-F). It shows a sharp drop in areas under large and medium farm holdings for *groundnut based crop livestock* system in Anantapur. In fact, this was attended by a proportional growth in total areas under marginal, small and semi-medium farms. Systems in arid ecosystem did show only mild change in this respect. The issue here is to comprehend what these changes in operational/enabling resources suggest for system function in terms of outputs, resources use efficiencies and future options of intensification across farm typologies.

Generally, fragmentation of holding is often cited as a reason for increased costs of production. Mahendra (2012) argues that marginal and small farms are labour intensive and thus the ratio of input to outputs is less affected compared to large farms. In reality, however, the majority of large farmers have access to canal irrigation, while marginal and small farmers are most often using bore-wells or have no access to water. In this case, small farm, for example with three plots, must sink three wells which are economically not feasible or alternatively buy water from adjacent farms. Irrigation might be delayed as the bore owner's own crop fields get priority for watering. This shows that the efficiency of marginal farm is contextual and as intensification is gaining a momentum there will be likelihood for increasing need of external inputs and thus high probability of shift in values of input to output ratio for marginal and small farmers.

At a point where land holding reaches a cut-off level beyond which it will neither accommodate family labour nor provide sufficient food, family members may exit that strategy and join alternatives if there are any. Most farmers have also other sources of livelihood that support their farming until they can exit agriculture all together. A good question is whether intensification by marginal and small farmers depends on this other investment or can be generated some other way and this needs examining farm size from livelihood assets perspective and such approach will help to target systems and livelihood for priority research and development.

Land use and land cover changes : effects on system structure and function

Other than population pressure agents such as climate change, international and local market and enabling environment (e.g. policy and availability of inputs like water) for alternative uses of land are frequently mentioned as an important agent of LULCC (Chaudhry *et al.* 2011). Regardless of the type of driving agent production systems in arid and semiarid ecosystems are experiencing a persistent LULCC and this has both environmental and livelihood implications (Chaudhry *et al.* 2011).

Figure 4A-B and Table 1 illustrate examples of LULCC in the study areas. In the *ground nut based crop- livestock system* and *pulses based crop- livestock systems*, major LULCC, during last decade, were conversion of range land to crop land. Additionally conversion from rain fed to irrigation also accounts for an important proportion. When we refer back to historical data (Figure 5), for these systems, more important changes were change in cropping pattern. For

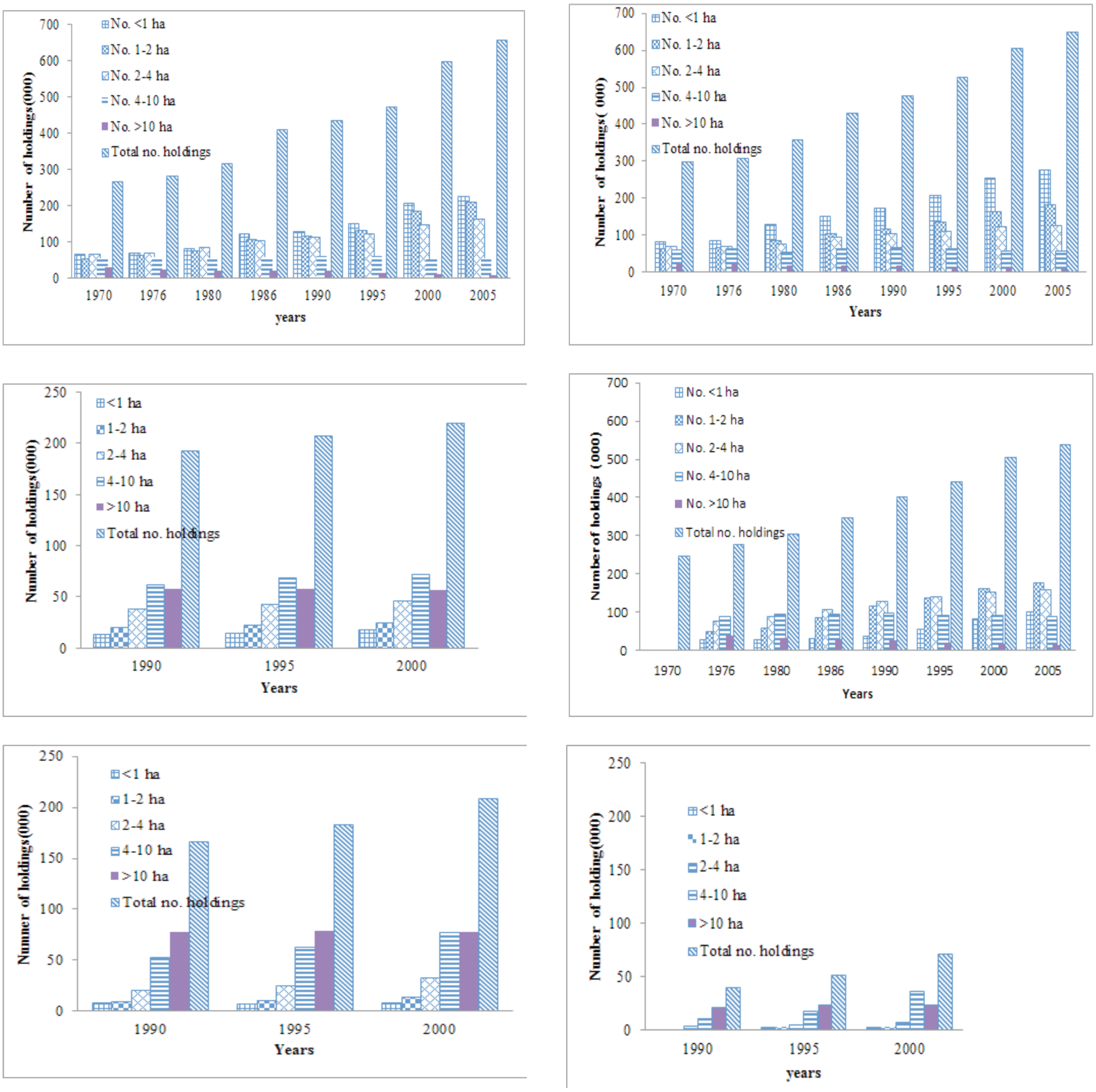


Figure 2A-F: Examples of trend in number of operational land holding by holding size across years in *groundnut based crop-livestock* production systems in Anantapur (A); *pulses based crop-livestock* production systems in Kurnool (B) C*ereals based crop-livestock* production systems in Bijapur (C); *millet based crop-livestock* production systems in Jodhpur (D) *small ruminant based crop-livestock* production system in Barmer (E) and *small ruminant based crop-livestock* production system in Jaisalmer *(F)*.

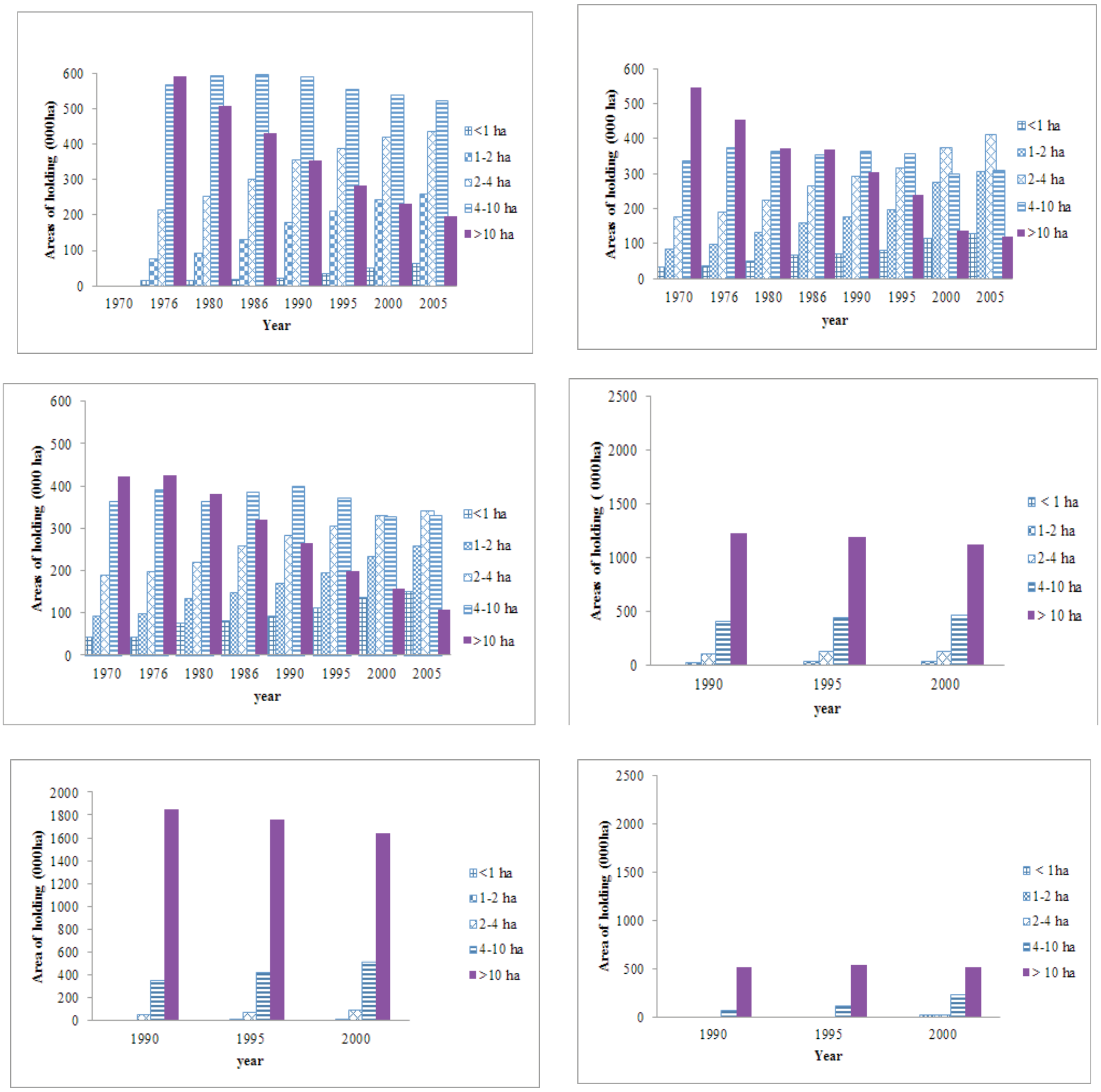


Figure 3A-F: Examples of trend in area of operational land holding by holding size in *groundnut based crop-livestock system* in Anantapur (A); *pulses based crop-livestock* production systems in Kurnool (B) *cereals based crop-livestock* production systems in Bijapur (C); *millet based crop-livestock* production systems in Jodhpur (D) *small ruminant based crop-livestock* production system in Barmer (E) and *small ruminant based crop-livestock* production system in Jaisalmer *(F).*

example many of the system moved clearly from traditional cereals based farming (millet and sorghum) to other crops (e.g. in Ananatpur and Kurnool). In absence of grazing land, quality of feed resources from the new crop determines the feed demand supply. While economically these changes can be efficient, depending on a single crop (e.g ground nut based crop-livestock system) is also controversial: as it damages the soil ecology and increases crop vulnerability to insects. The result is a more fragile ecosystem with an increased dependency on pesticides and artificial fertilizers.

Quite interesting here are the negligible areas of grazing lands in both livestock and crop dominant systems and a significant conversion of range lands and waste lands to crop lands. Generally wasteland and range lands are common property resources (Jodha 1986).

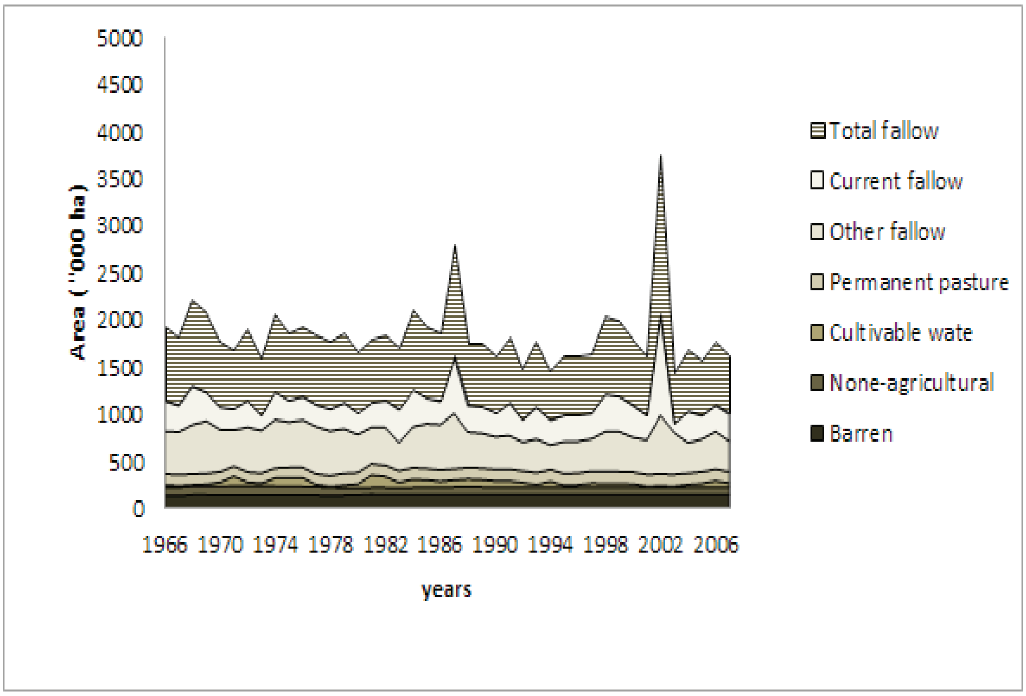
Table 1: Examples of Land Use Land Cover Changes (LULCC) between 2000 and 2010 for ground nut based crop- livestock system in Anantapur and pulses based crop- livestock system in Kurnool

	Extent of changes by crop livestock mixed systems (ha)	
Types of LULCC	**Pulses based**	**Ground nut based**
Rangelands to Rainfed-single crop	15,425	27,300
Rangelands to Irrigated- single crop/double crop	1,088	556
Irrigated-single crop to others	1,725	931
Irrigated-single crop to Irrigated double crop	11,813	450
Rainfed-single crop to Irrigated single or double crop	8,213	1,113
Rainfed-singe crop to others	19,125	7,081

And they are important livelihood sources for landless community who completely dependent on livestock. In arid areas it is in response to the need for unrestricted mobility of livestock that the common property resources or common access resources emerged as the dominant forms of resources ownership and usage by village and communities in this region (Jodha 1986). In view of these trends we argue that these changes restrict landless community to access these resources for their livestock grazing (Jodha 1986). On the other hand this transition is an opportunity for these individuals who are enjoying increased productivity as the results of improved input (irrigation and fertilizer) at least in short term.

5. Livelihood outcomes: quest for features of sustainable agriculture

Apparently, intensification of agricultural production has improved food which is one of the livelihood outcomes. Figure 6a-e depicts trend in major crop productivity across years in different dryland production systems. In the ground nut based crop livestock system, pulses based crop livestock system and cereals based crop-livestock system yield for major cereals has increased. While for the millet based crop livestock system and small ruminants based millet system the yield for major cereal crop tends to stagnate. Improvements in productivity of other crops were



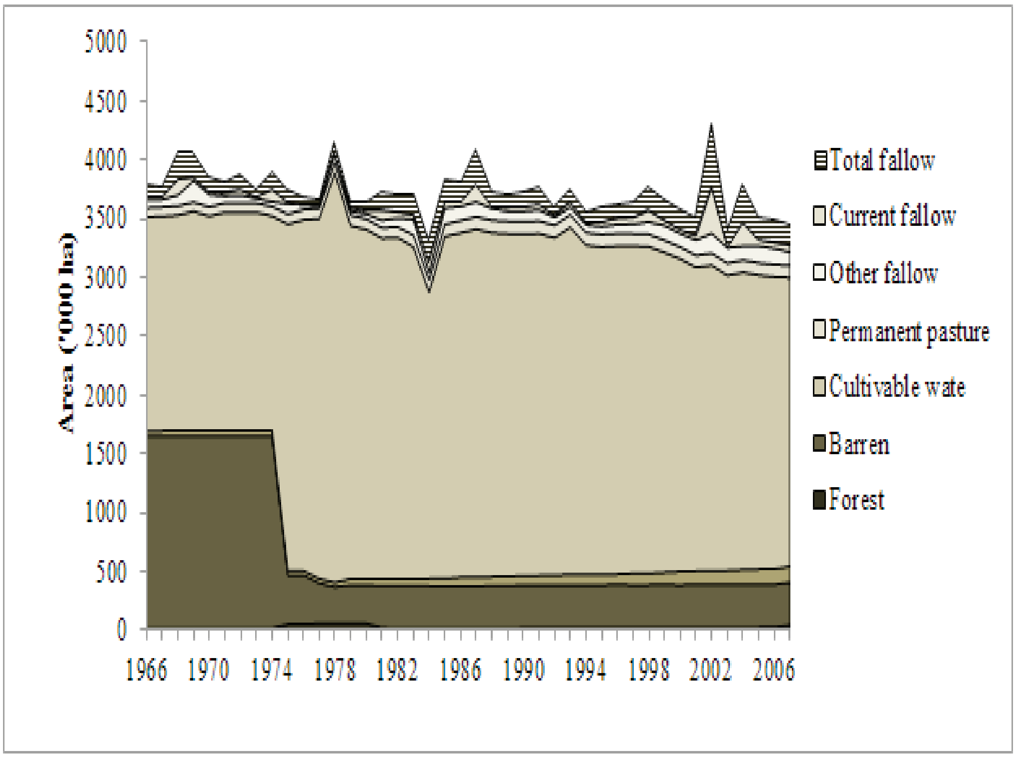


Figure 4 A& B: LULCC in *millet based crop-livestock* production systems in Jodhpur (A) and *small ruminant based crop-livestock* production system in Jaisalmer (B).

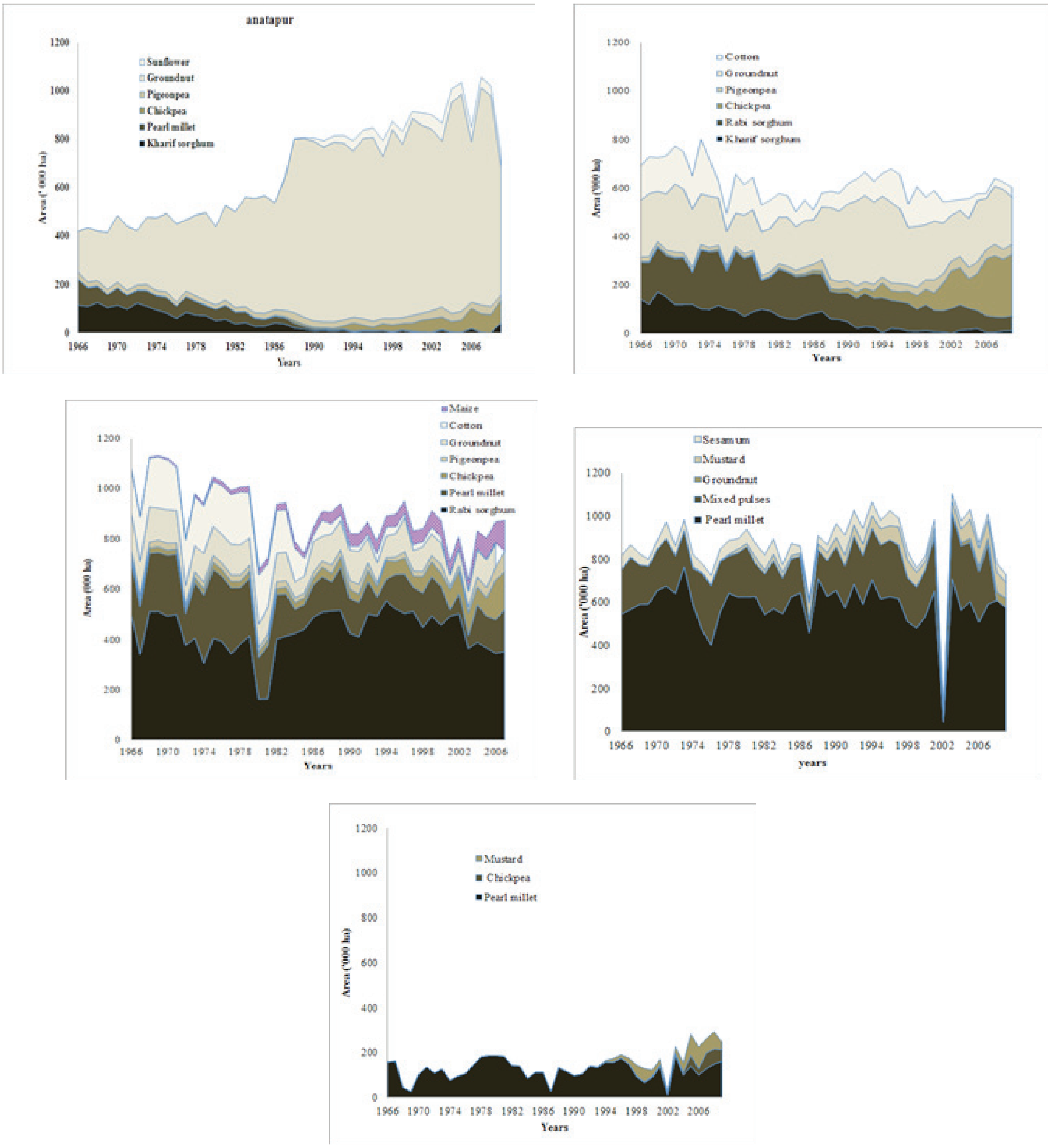


Figure 5A-E: Examples of trend in cropping pattern in groundnut based crop-livestock system in Anantapur (A); pulses based crop-livestock production systems in Kurnool (B) cereals based crop-livestock production systems in Bijapur (C); millet based crop-livestock production systems in Jodhpur (D) and small ruminant based crop-livestock production system in Jaisalmer (E).

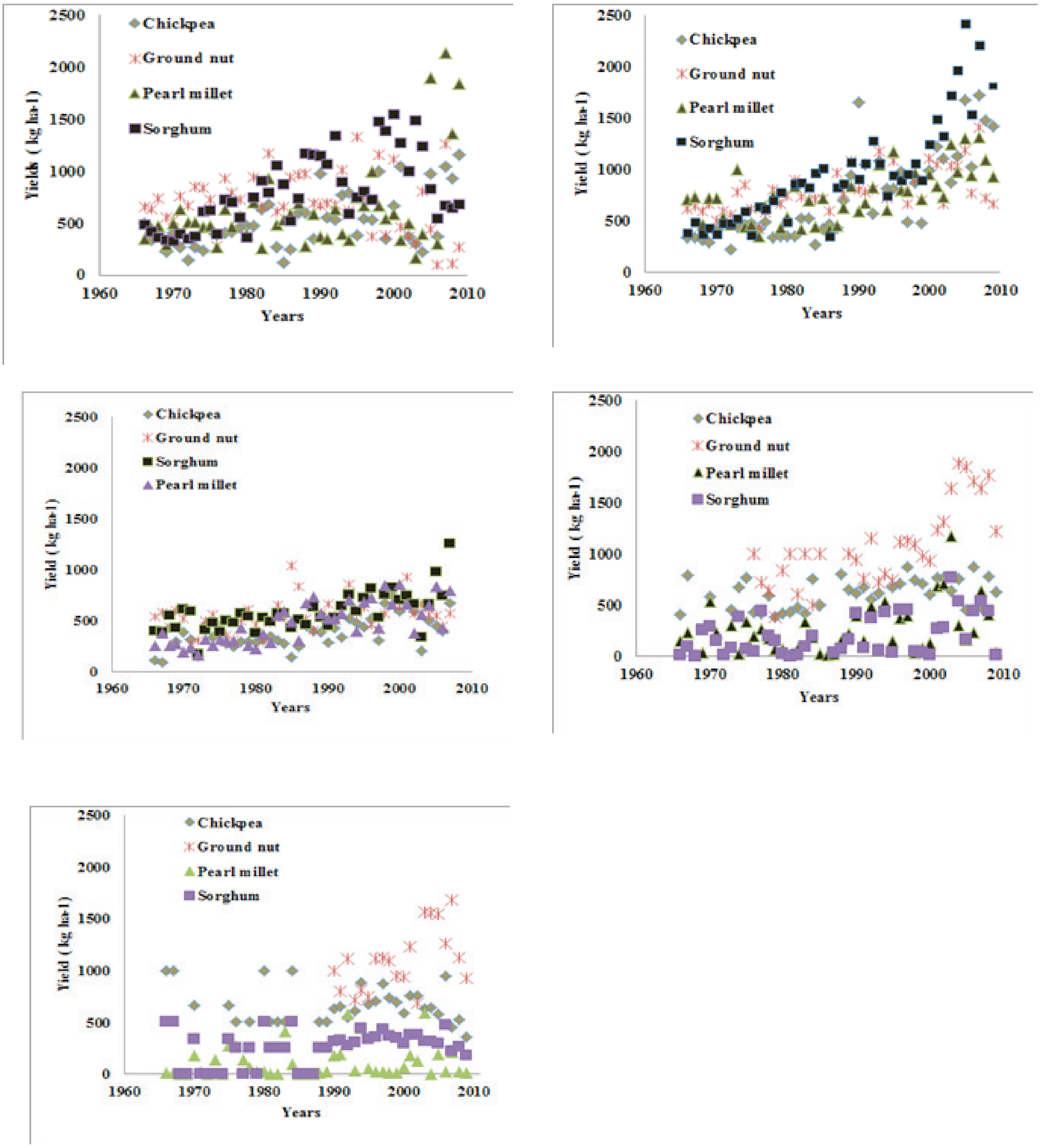


Figure 6A-E: Examples of trend in yields of selected dryland crops in groundnut based crop-livestock system in Anantapur (A); pulses based crop-livestock production systems in Kurnool (B) cereals based crop-livestock production systems in Bijapur (C); millet based crop-livestock production systems in Jodhpur (D) and small ruminant based crop-livestock production system in Jaisalmer (E).

not spectacular for all systems. For example the productivity of ground nut in system where it cover major area, tends to decline.

Quite interesting issue revealed from Figure 6 was also the huge intersystem and intrasystem variation of productivity. A coefficient of variation (CV) for major crops across and system ranged between 24 and 140% and the highest value was for cereals in the small ruminant based millet system. Perceptibly the intersystem variation can be explained by the differences in biophysical factors among these systems. Intrasystem disparity across years, as illustrated by wide range of CV, is an indicator of lack of system stability and therefore its poor sustainability (FAO 1997). The point here is to understand as to what drives such instability and decline in productivity of some of these crops and what researchers and policy makers can deliver to mitigate the adverse impacts of these trends.

A closer monitoring of some of the environmental sustainability indicators suggest that years of cultivation and unbalanced nutrient inputs depleted soil nutrient stocks in the mixed crop livestock systems in arid and semiarid ecosystems. For example Haileslassie *et al.* (2012) reported that about 79% of farmers' fields in semi-arid areas in Karnataka are deficient in organic carbon (OC) and 74% of farmers' fields showed deficiency in S. Fields used for pulses were the most deficient in P (45.28 % of the fields) and Zn (60.4% of the fields), while B deficiency was observed on 64.10% of fields used for oil crops. In fact this is an interplay of combination of factors: low input to counter balance the nutrient lost through erosion, leaching, and product outputs. The authors argue that the effects of such dwindling ecosystem production services provision goes beyond crop production. It affects livestock development mainly in terms of low feed availability and low feed quality associated with multi-nutrient deficiencies. When the historical LULCC, that consistently pushes the grazing land, is taken into account this, in fact, is 'a tip of an iceberg'. Future system research needs to consider nutrient as an interface of soil-plant-livestock.

Despite huge seasonal and regional variations, India should have ample water for agricultural, industrial and household use. But most of the rain falls in a short time, in the wrong places and in many places the use of irrigation water is reported as unsustainable. For example nearly a third of India's groundwater blocks were defined in 2004 as critical, semi-critical or over-exploited (Rodel *et al.* 2009). In the studied systems, coupled with other drivers, improved access to water as an input to agricultural production has triggered LULCC, and introduction of new varieties and probably one of the major causes for improved productivity. Reliance on rain fall and pocket wise exploitation of ground water and canal irrigation are distinctive characteristics of the studied areas. Practices of traditional rain water harvesting (e.g. Tanks, Khadien) are declining due to limiting biophysical factors or decline of institutions that have nurtured them, or have lost their relevance in the modern day context (Agarwal and Narain 1997).

But what is more often emerging as challenges to a sustainable water use, in these systems, is the ground water over exploitation. Analysis of public ground water data for the studied sites shows over exploitation of ground water in many areas (e.g. cereals based crop livestock systems in Bijapur). Discussion with farmers suggests that a remarkable proportion of the bore wells is drying out (Ananatapur, Kurnool and Bijapur) and thus substantiate the empirical evidences. Number of scholars ascribes the trend to imprudent water use (Rodel *et al.* 2009). In general this has a negative feedback to the enabling resources frontier and thus complicating prediction of future directions to where agricultural production system evolves.

6. Sustainable trajectory for agricultural development: the role of research

Despite lack of a comprehensive yield gap assessment (integrating nutrient, water and variety) many report huge crop yield gaps in arid and semiarid production systems and an example is provided on (Table 2). These reveal opportunities to improve the performances of agricultural development both in terms of environmental indicators and livelihood outcomes. Apparently, if water, the major production limiting factor in semiarid and arid ecosystem, was included in the analysis these yield gaps could have been even higher.

Table 2: Examples of nutrient and variety limited yield gaps arid ecosystems

District	**Rain fall (mm yr^{-1})**	**Yield (kg ha^{-1})**			
		Farmers practice	Farmers practice + improved varieties	Balanced nutrient + improved varieties	SED (5%)
Tonk	288	1150	1930	3160	280
Udaipur	570	2530	3090	6320	590
Mean of 5 districts		1810	2550	4320	

Similarly, examining livestock performances in terms of milk yield and weight gain under different feeding regimes demonstrates disparity between farmers' practices and improved management. Haileslassie *et al.* (2011) illustrated a significant increase in livestock products and services when feed sourcing (good quality feed), feeding techniques and livestock management were improved. When these feed sources are water productive the impact could be even multiple: improves livelihood and saves water and therefore ensures positive feedback to the enabling resources.

One of the major limitations, to get these technologies and ideas on farm and thereby straighten intensification trajectory in a way to meet features of sustainable agricultural production, lies not only in where research should focus but also how research engages the eventual users and promoters.

In summary, there are key questions that a system research should ask and pursue answers for to contribute towards efforts to achieve sustainable agricultural production in drylands. These include:

- What are the best strategies to involve and reach diverse partners and add value to local efforts?
- What is the nature and the level of vulnerability and potentials of the different production systems?
- What are respective technical (e.g. components mix) and institutional measures (e.g. for common property resources management) needed to increase resilience and close the yield gaps and what are the potential trade-offs?
- Which biophysical and social landscapes (e.g. marginal, large farmers) should be targeted and what respective incentive measures are needed to enable farmers to pursue judicious uses of resources?

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Vulnerability and agricultural intensification in drylands - an alternative framework for development research

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Extended abstract

Despite decades of investment in research and development in dryland areas around the globe challenges of underdevelopment, chronic food insecurity, and poverty persist, and are now increasingly exacerbated by climate change. The scarcity of progress in dryland development is aggravated by a lack of clarity around whether development objectives should aim primarily to reduce vulnerability or to promote intensification. Vulnerability and intensification are typically assumed to lie on the same continuum, so that a household with a high level of vulnerability is assumed to have low potential for intensification, and vice versa. The same idea is also applied at larger scales to communities and regions. This widespread view ignores the dynamic nature of vulnerability in drylands and the opportunities for sustainably enhancing livelihoods and food security through alternative development pathways. Development targeting and research in the drylands must take account of vulnerability and potential for intensification, but must avoid oversimplifying the relationship between the two.

We propose an analytical framework for agricultural research and development in the drylands which recognizes that vulnerability and potential for intensification are two separate variables rather than two extremes of a single dimension. Furthermore, the framework involves a multi-dimensional characterization of production systems and vulnerability emerging from overlapping and interactive gradients at multiple spatial and temporal scales. The framework provides an alternative lens for conceptualizing the challenges of dryland development and can help to guide development research, including research for impact assessment, by highlighting categories of data that should be collected at various levels from the individual to the national level. Similarly, the framework highlights the importance of a multi-dimensional approach to effective and sustainable dryland development that combines vulnerability reduction with productivity increases for enhanced incomes, nutrition, food security, and ecosystem services.

Sampling the vulnerability reduction– sustainable intensification continuum: a West African paradigm for selection of *Dryland Systems* sites

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Abstract

The CGIAR Research Program on Dryland Systems (hereafter *Dryland Systems*) initially segregated world regions into vulnerability reduction (strategic research theme 2 = SRT2) and sustainable intensification (SRT3) domains based on aridity index (AI) ranges (SRT2 = [0.03-0.35], SRT3 = [0.35-0.65]). While acceptable on global and continental scales, this simple approach is insufficient to adequately represent the diversity of systems trajectories observed in the West African drylands. In this paper, we argue that this may lead to sub-optimal research targeting, as the SRT2 – SRT3 continuum could be expressed on a variety of temporal and spatial scales in relative independence from the aridity factor. We provide illustrations of this impact at a regional scale for West Africa. We propose that *Dryland Systems* site selection in the West African drylands should reflect (i) the dominantly socio-economic nature of drivers of change; (ii) dynamic longitudinal population density gradients across a quasi-invariant, largely monotonic meridional climate gradient; (iii) the cost efficiencies of sampling spatial gradients with complementary action transects that maximize the regional representativeness of *Dryland Systems* sites. Burkina Faso, Ghana, Mali, Niger and Nigeria are selected as *Dryland Systems* countries. Two action transects are identified: the Kano-Katsina-Maradi (KKM) transect, with contrasted biophysical conditions from the Sahel to the Sudan savanna, and somewhat more homogeneous socio-economic conditions; and the contrasting and complementary Wa-Bobo-Sikasso (WBS) transect, with diverse socio-economic conditions against a more homogenous biophysical backdrop. Two satellite sites expand the regional representativeness of each transect biophysically (WBS) and socio-economically (KKM). This regional paradigm ensures that site selection (i) is made along the strongest gradients, effective spatial proxies for the temporal drivers of change that define SRT potential; (ii) discretely captures local systems variability, i.e. real-world SRT expression at community-to-district scales where smallholders operate, and (iii) therefore reflects the portability over space and time of the *SRT2* ⇔ *SRT3* continuum.

Introduction

Dryland agricultural systems in West Africa are largely rainfed covering a diverse mix of food, fodder and fiber crops; vegetables, rangeland and pasture species; fruit and fuel-wood trees; medicinal plants; livestock and fish (Lamien *et al.* 2012). Dryland agricultural production systems in the region are characterized by persistent droughts, water scarcity, rapid population growth, climatic variability, land degradation and desertification, and widespread poverty. To enhance the livelihoods of dryland farming communities, it is critical to manage risk more effectively and improve productivity through sustainable intensification of production systems and diversification of livelihood strategies. Past experience clearly shows that an integrated approach is important:

better management of natural resources, improvement of crop, vegetable, livestock, and tree production supported by an enabling policy environment and institutions.

The CGIAR Research Program on Dryland Systems (hereafter *Dryland Systems*) is targeted at the poor and highly vulnerable populations of the dry areas, and aims to develop technology, policy and institutional innovations to improve food security and livelihoods using an integrated systems approach (ICARDA 2012). It aims to deliver technology in a context that meets the daily reality of smallholder farming communities, with a more holistic approach to understand complex system interactions and key factors that drive system-level processes or constrain growth in productivity.

Dryland Systems classifies production systems into two broad categories based on both biophysical and socio-economic criteria: (i) those with the deepest endemic poverty and most vulnerable people (Strategic Research Theme 2, hereafter SRT2); and (ii) those with the high potential to contribute to food security and grow out of poverty in the short to medium term (SRT3). In SRT2, *Dryland Systems* emphasizes increasing resilience and mitigating risk from biophysical and socioeconomic shocks despite marginal conditions. In SRT3, sustainable intensification of production systems is proposed to improve livelihoods.

The distinction between these two categories is somewhat arbitrary: they are not mutually exclusive and many dryland systems will contain areas or elements of both. However, the initial process of site selection relies heavily on segregating SRT2 and SRT3 benchmark areas based on assumed differences in aridity only. In this paper, we argue that this double contradiction may lead to suboptimal research targeting, as the SRT2 – SRT3 continuum expresses on a variety of temporal and spatial scales in relative independence from the aridity factor. We provide illustrations of this impact at a regional scale for West Africa.

Materials and methods

Area of interest: This paper focuses on the 'West African Sahel and Dry Savannas' region of *Dryland Systems*. For reasons of agro-climatic, production systems similarity and geographical proximity, Cameroon, Chad and the Central African Republic are included in the regional set of candidate countries for *Dryland Systems*. Island nations (Cape Verde, Sao Tome and Principe) are not included and the focus is hence solely on continental West and Central Africa. Within that area of interest, drylands are defined by the aridity index (AI) range of 0.03-0.65 (ICARDA 2012).

GIS data: The *Dryland Systems* proposal (ICARDA 2012) provides 25 biophysical and 16 socio-economic variables for identifying target areas (Table 1). For many, much of the corresponding data are not available in the public domain as spatially comprehensive and continuous GIS layers of sufficient granularity. However, many proposed variables actually co-vary, and on a regional scale a subset of a few key variables can probably capture most of the variability in SRT2-SRT3 conditions. Since we are only interested in substantiating a simple site selection process with spatial evidence, we chose to focus only on: (i) poverty as the defining indicator for SRT2, SRT3; (ii) aridity index as the proposed criterion for delineation of corresponding benchmark areas; and (iii) population density as an alternative or complementary information source for site selection.

Table 1: Non-exhaustive listing of selection criteria for identifying Dryland Systems CRP target areas (ICARDA, 2012)

Biophysical (n=25)	**Socioeconomic (n=16)**
Accessibility: closeness to partners headquarters, proximity to research facilities	Demography: population, poverty, employment (e.g. women/men differential aspects), nutrition status
Climate: rainfall patterns, temperature profile, drought and heat indices, length of growing period, elevation	Access to markets: distance, size, competitiveness
Soils: nutrient-supply capacity, water-holding capacity, morphology, soil erodability, degradation / desertification	Access to water and land: communal/private ownership, pricing, access
Biotic stresses: diseases, pests, weeds (e.g. *Striga* spp.)	Gender and disadvantaged groups' responsiveness: differential aspects, absolute aspects
Farming systems: crops, vegetables, livestock, trees, mixed systems, gap between actual economic and potential yields	Governance, institutions, and policy: inclusiveness of stakeholders, equity, accountability, transparency
Sensitivity to global change: climate (variation and change parameters), globalization	
Land degradation: physical, chemical	

Approach: Our mandated target output is the identification of two action sites, each with satellite sites. Initial consultations suggested that we limit the number of *Dryland Systems* countries to five, as is the case for the Climate Change, Agriculture and Food Security CRP (CCAFS). We first extract dryland fractional areas and population counts per country, relative to national and regional areas and populations. A simple ranking allows us to prioritize target countries for *Dryland Systems* deployment. We then mapped poverty patterns using best available sub-national data, and assessed their macro-scale correlation with biophysical (aridity index) and socioeconomic (population density) variables. The intent was to explore whether aridity (population) is a good enough predictor of poverty, capable of informing the sampling of SRT2 and SRT3 conditions. We also examined the frequency distributions of aridity index and population density values for natural breakpoints (Jenks 1967) within the domain of interest, to propose representative threshold values for regional stratification.

We then mapped proposed thresholds with corresponding aridity and population gradients, to document where high spatial rates of change are observed, and identify action transects across priority countries where probable variations in SRT2-SRT3 conditions can be sampled at a lower cost. The regional representativeness of two proposed multi-district action transects is finally compared to a hypothetical alternative choice of two action sites of equivalent area, selected within 'homogeneous' SRT2 and SRT3 strata defined by different aridity levels.

Results

Drylands coverage: On an area basis, Figure 1 and Table 2a showed that just over half of continental West and Central Africa belongs to drylands. Mali (19.6%), followed by Chad (18.0%), Niger (13.4%) and Nigeria (12.4%) collectively account for 2/3 of the region's drylands. Mali holds the largest dryland area coverage with over 850,000 km2. Out of 18 countries investigated, 8 record more than half their national landmass under drylands: Benin, Burkina Faso, Chad, the Gambia, Mali, Nigeria, Senegal, and Togo. Drylands cover more than 1/3 of national area in an additional 4 countries: Ghana, Ivory Coast, Mauritania, and Niger.

On a population basis and using Landscan2001™ data from UT-Battelle (2001), drylands host 128,020,275 inhabitants, 47.9% of the region's population (Table 2b). Of these, Nigeria contributes the largest share (39.2%) followed by Burkina Faso (9.6%), Mali (8.6%) and Niger (8.0%). A simple composite ranking of the importance of drylands per country, relative to area and population counts on both national and regional levels identified a cluster of 8 priority countries, with Burkina Faso and Mali ranking first; Niger third; Chad, the Gambia, Nigeria, and Senegal fourth; and Benin eighth. This ranking was used to provide a first cut of 4 countries for *Dryland Systems*. As a fourth country, Nigeria was chosen owing to its large dominance at a regional level, especially for population size.

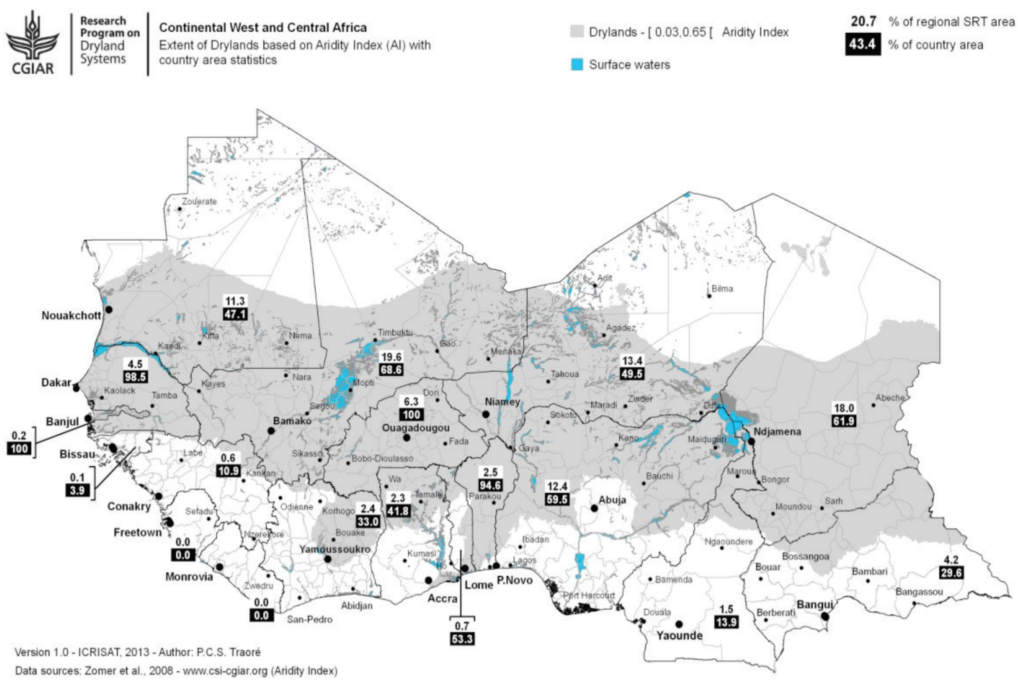

Figure 1: Continental West and Central Africa. Extent of *Dryland Systems* domain as defined by the Aridity Index with country statistics.

Poverty patterns: Fundamentally, poverty levels define the difference between SRT2 and SRT3 systems . Compared to percent total population counts (Table 2b), percent poor population counts based on best available sub-national data (Table 3) indicate that poor populations living on less than $1.25 per day tend to concentrate in the drylands. This is most explicit for climatically contrasted coastal countries: in Nigeria (Ghana, Benin) for example, drylands host 39.7% (34.7%, 62.9%) of total population, but gather 43.1% (46.2%, 77.4%) of the poor.

Within the West African drylands however, Figure 2 showed that the spatial distribution of poverty did not depend on latitude. Correlation analysis confirmed it is indeed independent from the latitudinally distributed aridity index, but also unrelated to population density: high poverty was observed in high density (Northern Nigeria), low density (Northern Benin), high aridity (Zinder region, Niger), and low aridity (Kwara State, Nigeria) areas. Conversely, lower poverty seems present in high density (Senegal), low density (South West Burkina Faso), high aridity (Mauritania), and low aridity (Niger State, Nigeria) conditions. Based on best available data, it is therefore no more (no less) justifiable to stratify poverty levels with aridity index than population density to predict the occurrence of SRT2 or SRT3 conditions in the West African drylands.

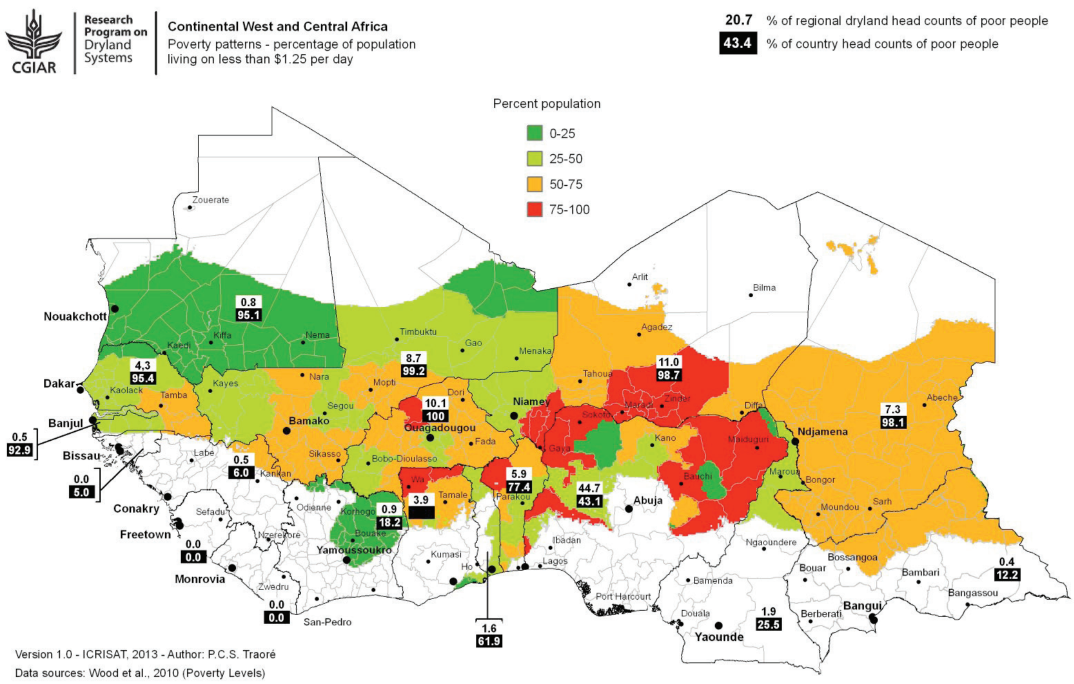

Figure 2: Continental West and Central Africa. Poverty patterns – percentage of population living on less than $1.25 per day.

Aridity and population patterns: Spatial patterns over the West African drylands are contrasted with a smooth, almost monotonic latitudinal gradient for aridity (Figure 3a: 1-km resolution, source: Zomer *et al.* 2008) and a more complex spatial arrangement for population (Figure 3b: 1-km resolution, source: UT-Battelle 2001) as a non-linear function of both longitude and latitude. At a very rough level, the latter can be approximated as two sub-regions beneath the agro-ecological gradient: a Western part, with lower population densities, and an Eastern part, with highly populated areas (Figure 4a). Depending on whether the (highly populated) dryland coastal savanna regions of Ghana, Togo and Benin are included in computations or not, aridity index explains between 2 and 5% of population variability within West African drylands: on a fine scale, the two factors are uncorrelated.

Stratification into SRTs: Aridity index and population density follow power law distributions (Jenks 1967): any classification is proposed for practical convenience but not statistically justified by the existence of two or more populations or values. In particular, stratification using natural breaks (Jenks 1967) showed sensitivity to extreme values. Truncating population densities to the [20:200] hab.km^2 range excluded heavy head (very sparsely populated areas) and tails (urban areas), and yielded more stable breakpoints around 70 hab.km^2 (Table 4). Between Burkina Faso, Ghana, Mali, Niger, Nigeria and Senegal, Senegal and Ghana are the countries most representative of the entire West African drylands for population density. Senegal is the country where the aridity breakpoint is naturally closest to the proposed threshold of 0.35.

The aridity (population) threshold values of 0.35 (70 hab.km^2) can be used to segregate the region into four strata of low-low, low-high, high-low, and high-high conditions (Figure 5). The low-low stratum is dominated by pastoralism with agriculture geographically limited to few landscape locations where water is available. This stratum was deemed of low priority due to limited target populations, further compounded by limited accessibility and recent security issues. Since only two action sites (each with a maximum of two satellite locations) are allowed in each hypothetical *Dryland Systems* geography, and since we target 5 countries including Burkina Faso, Ghana, Mali, Niger and Nigeria, the only way to sample the remaining three strata in 5 countries is to rely on cross-boundary transects.

Action transects: The non-uniform aridity and population surfaces for the West African drylands do not lend themselves to random sampling. Being continuous and uni-modal, they can be (somewhat arbitrarily) discretized using distribution breakpoints, but are more efficiently and systematically sampled using transects along environmental gradients. Two cross-boundary transects are proposed that sample the 3 strata with at least one 'high' factor: the North-South Kano-Katsina-Maradi transect (KKM: Niger-Nigeria), and the East-West Wa-Bobo-Sikasso transect (WBS: Ghana-Burkina Faso-Mali). Given the geographical configuration of national boundaries and the 5 countries limit, Niger-Nigeria only provides a North-South setup, and Ghana is the only available option to extend a longitudinal Burkina-Mali transect while remaining logistically tractable, i.e. travelable overland within one day between its two most distant extremities (Figure 5).

Significant differences were observed between KKM and WBS in the population densities and aridity conditions sampled for both large (~80,000 km^2) and small (~4,000 km^2) transects (Table 5). It also illustrates that adequate directional transects, both generic and indexed to administrative boundaries are far more efficient than compact designs at sampling a large range of variability in strong environmental gradients, such as the aridity index.

Table 5 also revealed that population can still vary significantly on a latitudinal gradient despite being uncorrelated with the aridity index. In fact, variability in population densities expresses isotropically, but on much smaller scales than variability in the aridity index.

The KKM and WBS transects are therefore orthogonally contrasted in terms of mean aridity index (KKM: low, WBS: high) and population density (KKM: high, WBS: low) but exhibit parallel patterns in the sampled variability of aridity index (KKM: high, WBS: low) and population density (KKM: high, WBS: low). Over space and at ± 1 standard deviation from each factor mean (Figure 5), the KKM transect is representative of an area of 830,485 km^2, a larger (19%) fraction of the West African drylands compared to the WBS transect (deemed representative of 371,131 km^2 or 8.5%): this follows from the fact that KKM runs along the main biophysical and population density gradient, while WBS runs orthogonal to the same, and only in the western, lower population density part of the region (Figure 4a). In contrast, the diversity of dominant language clusters (and underlying agricultural systems) intersected by the same transects increases tenfold: from barely 3 in KKM to 34 in WBS (Figure 6).

Table 2a: RT and Drylands (SRT2+SRT3) area extent by country, continental West and Central Africa. SRT2 (SRT3) corresponds here to dryland regions with an aridity index inferior (superior) to 0.35

Country[1]	**BEN**	**BFA**	**CAF**	**CIV**	**CMR**	**GHA**	**GIN**	**GMB**	**GNB**	**LBR**
Area (km2)										
SRT2	1331	104844	6919	0	14103	0	0	1730	0	0
SRT3	108171	169640	176160	106042	50959	99788	26610	8515	1331	0
SRT2+SRT3	109501	274484	183078	106042	65062	99788	26610	10245	1331	0
Other	6253	0	435609	215144	401548	138772	217272	0	32864	96595
Total	115754	274484	618687	321185	466610	238561	243883	10245	34194	96595
Country area (%)										
SRT2	1.1	38.2	1.1	0.0	3.0	0.0	0.0	16.9	0.0	0.0
SRT3	93.4	61.8	28.5	33.0	10.9	41.8	10.9	83.1	3.9	0.0
SRT2+SRT3	94.6	100.0	29.6	33.0	13.9	41.8	10.9	100.0	3.9	0.0
Other	5.4	0.0	70.4	67.0	86.1	58.2	89.1	0.0	96.1	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Region SRT area (%)										
SRT2	0.0	3.9	0.3	0.0	0.5	0.0	0.0	0.1	0.0	0.0
SRT3	6.4	10.0	10.4	6.3	3.0	5.9	1.6	0.5	0.1	0.0
SRT2+SRT3	2.5	6.3	4.2	2.4	1.5	2.3	0.6	0.2	0.0	0.0
Other	0.2	0.0	10.8	5.3	9.9	3.4	5.4	0.0	0.8	2.4
Total	*1.4*	*3.3*	*7.4*	*3.8*	5.6	2.8	2.9	0.1	0.4	1.1

Country[1]	**MLI**	**MRT**	**NER**	**NGA**	**SEN**	**SLE**	**TCD**	**TGO**	**Total**
Area (km2)									
SRT2	641439	491224	584892	154738	116154	0	551097	0	2668472
SRT3	215010	0	1730	385582	78234	0	235766	30336	1693873
SRT2+SRT3	856450	491224	586622	540320	194388	0	786864	30336	4362345
Other	392634	550698	597665	367487	2927	72646	484173	26610	4038898
Total	1249083	1041923	1184287	907807	197315	72646	1271037	56946	8401242
Country area (%)									
SRT2	51.4	47.1	49.4	17.0	58.9	0.0	43.4	0.0	327.5
SRT3	17.2	0.0	0.1	42.5	39.6	0.0	18.5	53.3	538.7
SRT2+SRT3	68.6	47.1	49.5	59.5	98.5	0.0	61.9	53.3	866.2
Other	31.4	52.9	50.5	40.5	1.5	100.0	38.1	46.7	933.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1800.0
Region SRT area (%)									
SRT2	24.0	18.4	21.9	5.8	4.4	0.0	20.7	0.0	100.0
SRT3	12.7	0.0	0.1	22.8	4.6	0.0	13.9	1.8	100.0
SRT2+SRT3	19.6	11.3	13.4	12.4	4.5	0.0	18.0	0.7	100.0
Other	9.7	13.6	14.8	9.1	0.1	1.8	12.0	0.7	100.0
Total	14.9	12.4	14.1	10.8	2.3	0.9	15.1	0.7	100.0

[1]ISO 3-letter country codes: BEN: Bénin; BFA: Burkina Faso; CAF: République Centrafricaine; CIV: Côte d'Ivoire; GHA : Ghana; IN : Guinée; GMB : The Gambia; NB : Guinea Bissau; LBR : Liberia; MLI : Mali ; MRT : Mauritania; NER : Niger; NGA : Nigeria; SEN : Sénégal; SLE: Sierra Leone; TCD: Tchad; TGO: Togo

Table 2b: SRT and Drylands (SRT2+SRT3) population counts by country, continental West and Central Africa. SRT2 (SRT3) corresponds here to dryland regions with an aridity index inferior (superior) to 0.35

Country[1]	**BEN**	**BFA**	**CAF**	**CIV**	**CMR**	**GHA**	**GIN**	**GMB**	**GNB**	**LBR**
Population counts										
SRT2	8684	4676730	6609	0	615446	0	0	147093	0	0
SRT3	4130890	7602410	390915	3055100	3218390	6885970	446000	1143510	55569	0
SRT2+SRT3	4139574	12279140	397524	3055100	3833836	6885970	446000	1290603	55569	0
Other	2440220	0	3185920	13279700	11944700	12950900	7050440	24117	120 780	3193890
Total	6579794	12279140	3583444	16334800	15778536	19836870	7496440	1314720	1260349	3193890
Country population counts (%)										
SRT2	0.1	38.1	0.2	0.0	3.9	0.0	0.0	11.2	0.0	0.0
SRT3	62.8	61.9	10.9	18.7	20.4	34.7	5.9	87.0	4.4	0.0
SRT2+SRT3	62.9	100.0	11.1	18.7	24.3	34.7	5.9	98.2	4.4	0.0
Other	37.1	0.0	88.9	81.3	75.7	65.3	94.1	1.8	95.6	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Region SRT population counts (%)										
SRT2	0.0	9.3	0.0	0.0	1.2	0.0	0.0	0.3	0.0	0.0
SRT3	5.3	9.8	0.5	3.9	4.1	8.9	0.6	1.5	0.1	0.0
SRT2+SRT3	3.2	9.6	0.3	2.4	3.0	5.4	0.3	1.0	0.0	0.0
Other	1.8	0.0	2.3	9.5	8.6	9.3	5.1	0.0	0.9	2.3
Total	2.5	4.6	1.3	6.1	5.9	7.4	2.8	0.5	0.5	1.2

Country[1]	**MLI**	**MRT**	**NER**	**NGA**	**SEN**	**SLE**	**TCD**	**TGO**	**Total**
Population counts									
SRT2	5469640	2550410	10207400	14589300	7959140	0	4156410	0	50386862
SRT3	5498410	0	57049	35607900	1810720	0	4467650	3262930	77633413
SRT2+SRT3	10968050	2550410	10264449	50197200	9769860	0	8624060	3262930	128020275
Other	34719	194221	88238	76096600	362676	5207180	79381	1850860	139188542
Total	11002769	2744631	10352687	126293800	10132536	5207180	8703441	5113790	267208817
Country population counts (%)									
SRT2	49.7	92.9	98.6	11.6	78.6	0.0	47.8	0.0	18.9
SRT3	50.0	0.0	0.6	28.2	17.9	0.0	51.3	63.8	29.1
SRT2+SRT3	99.7	92.9	99.1	39.7	96.4	0.0	99.1	63.8	47.9
Other	0.3	7.1	0.9	60.3	3.6	100.0	0.9	36.2	52.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Region SRT population counts (%)									
SRT2	10.9	5.1	20.3	29.0	15.8	0.0	8.2	0.0	100.0
SRT3	7.1	0.0	0.1	45.9	2.3	0.0	5.8	4.2	100.0
SRT2+SRT3	8.6	2.0	8.0	39.2	7.6	0.0	6.7	2.5	100.0
Other	0.0	0.1	0.1	54.7	0.3	3.7	0.1	1.3	100.0
Total	4.1	1.0	3.9	47.3	3.8	1.9	3.3	1.9	100.0

[1]ISO 3-letter country codes: BEN: Bénin; BFA: Burkina Faso ; CAF: République Centrafricaine ; CIV: Côte d'Ivoire; GHA : Ghana; GIN : Guinée; GMB : the Gambia; GNB : Guinea Bissau; LBR : Liberia ; MLI : Mali ; MRT : Mauritania ; NER : Niger; NGA : Nigeria; SEN : Sénégal; SLE: Sierra Leone; TCD: Tchad; TGO: Togo

Discussion

Poverty as a predictor of SRT2 or SRT3: Variable levels of heterogeneity are observed in the spatial distribution of poverty levels – in part due to variable data granularity levels from one country to another: 13, 12, 11, 7, 10, 9, 13, 8, 37, and 19 sub-national units contributed respectively for Burkina Faso, Cameroon, Cote d'Ivoire, the Gambia, Mali, Mauritania, Niger, Nigeria, and Senegal (Carlo Azzarri, IFPRI, pers. comm., 2012). While underlying data mostly comes from nationally representative and trustworthy household surveys conducted around 2005, variation in reporting unit size certainly blurs the relationship between poverty levels and other potential prognostic, more granular variables for SRT2 and SRT3 conditions such as aridity index and population density. Correlation is higher with population density than with aridity, but remains non significant and cannot substantiate the use of population density as a predictor of poverty, reflecting the complex, scale-dependent link between poverty and population density (Tinsley & Bishop 2006). In fact, the coarse granularity of poverty data directly reflects the longstanding macro-economic emphasis of poverty alleviation policies, which has itself shown its limits (Barrett *et al.* 2006).

Climate alone is not granular enough: Agricultural development challenges in West African drylands have traditionally been analyzed through the prism of biophysical constraints in the wake of the "environmental urgency" myth that arose from the strongest desiccation event on meteorological record: 1950-1990 (Batterbury & Warren 2001). The whole region has long and misleadingly been labeled as "the Sahel", perpetuating the deceptive image of a relatively homogeneous entity, climate and systems-wise. The reality is that the region hosts an enormous variety of biophysical environments (Vlek 1995) and extremely contrasted socio-economic, demographic and land use conditions (Raynaut 2001).

A climate-based approach to site selection thus faces two potential challenges: first, it tends to implicitly condone "one-size-fits-all" (wide adaptation paradigm) as an acceptable solution for entire strategic benchmarking (SRT2 and SRT3), because climate gradients are shallow and cover very large areas wherever terrain is flat. Such an approach would mirror an environmentally driven, top-down reductionism characteristic of sectoral research entailed with the risk of un-adapted and un-adoptable 'solutions' for smallholder settings. Second, it puts emphasis on a structuring (mostly static) feature of agricultural systems, not on a (dynamic) driver of change. This focus is likely to lead to unsustainable solutions to the food security and poverty reduction challenges, which would be in stark contradiction with research for development objectives. Targeting of interventions based on climate-based criteria such as the aridity index only (or derivatives such as agro-ecological zones) may already miss out on important systemic patterns at aggregate levels of scale, very early in the site identification process, because they leave aside the socio-economic context that presides over system change. The same way that 'science needs to be brought into the system, rather than the system into the science' (Mortimore *et al.* 2000), action sites need to be activated within a context, rather than an externally determined context within sites.

Drivers of change are mostly socio-economic: A relevant drylands system research strategy in West Africa must obviously cut across agro-ecologies (Sahelian, Sudanian, Guinean) that carry very different agricultural development opportunities. Within that framework, population density

Table 3: SRT and Drylands (SRT2+SRT3) head counts living below \$1.25/day, continental West and Central Africa. SRT2 (SRT3) corresponds here to dryland regions with an aridity index inferior (superior) to 0.35

Country[1]	BEN	BFA	CAF	CIV	CMR	GHA	GIN	GMB	GNB	LBR
Head counts										
SRT2	8416	3751670	5835	0	275122	0	0	47221	0	0
SRT3	3035070	5217780	325367	791155	1383930	3441420	425296	376178	33830	0
SRT2+SRT3	3043486	8969450	331202	791155	1659052	3441420	425296	423399	33830	0
Other	888452	0	2383560	3561420	4849740	4008110	6687520	32205	640835	3482210
Total	3931938	8969450	2714762	4352575	6508792	7449530	7112816	455604	674665	3482210
Country head counts (%)										
SRT2	0.2	41.8	0.2	0.0	4.2	0.0	0.0	10.4	0.0	0.0
SRT3	77.2	58.2	12.0	18.2	21.3	46.2	6.0	82.6	5.0	0.0
SRT2+SRT3	77.4	100.0	12.2	18.2	25.5	46.2	6.0	92.9	5.0	0.0
Other	22.6	0.0	87.8	81.8	74.5	53.8	94.0	7.1	95.0	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Region SRT head counts (%)										
SRT2	0.0	10.1	0.0	0.0	0.7	0.0	0.0	0.1	0.0	0.0
SRT3	5.9	10.2	0.6	1.5	2.7	6.7	0.8	0.7	0.1	0.0
SRT2+SRT3	3.4	10.1	0.4	0.9	1.9	3.9	0.5	0.5	0.0	0.0
Other	1.1	0.0	2.9	4.3	5.8	4.8	8.0	0.0	0.8	4.2
Total	2.3	5.2	1.6	2.5	3.8	4.3	4.1	0.3	0.4	2.0

Country[1]	MLI	MRT	NER	NGA	SEN	SLE	TCD	TGO	Total
Head counts									
SRT2	3008530	687116	9637500	14344000	2900330	0	2633210	0	37298950
SRT3	4667490	0	87071	25222300	866132	0	3858240	1431060	51162319
SRT2+SRT3	7676020	687116	9724571	39566300	3766462	0	6491450	1431060	88461269
Other	65427	35575	132196	52287400	182848	3183980	124449	880691	83426618
Total	7741447	722691	9856767	91853700	3949310	3183980	6615899	2311751	171887887
Country head counts (%)									
SRT2	38.9	95.1	97.8	15.6	73.4	0.0	39.8	0.0	21.7
SRT3	60.3	0.0	0.9	27.5	21.9	0.0	58.3	61.9	29.8
SRT2+SRT3	99.2	95.1	98.7	43.1	95.4	0.0	98.1	61.9	51.5
Other	0.8	4.9	1.3	56.9	4.6	100.0	1.9	38.1	48.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Region SRT head counts (%)									
SRT2	8.1	1.8	25.8	38.5	7.8	0.0	7.1	0.0	100.0
SRT3	9.1	0.0	0.2	49.3	1.7	0.0	7.5	2.8	100.0
SRT2+SRT3	8.7	0.8	11.0	44.7	4.3	0.0	7.3	1.6	100.0
Other	0.1	0.0	0.2	62.7	0.2	3.8	0.1	1.1	100.0
Total	4.5	0.4	5.7	53.4	2.3	1.9	3.8	1.3	100.0

[1]ISO 3-letter country codes: BEN: Bénin; BFA: Burkina Faso ; CAF: République Centrafricaine ; CIV: Côte d'Ivoire; GHA : Ghana; GIN : Guinée; GMB : the Gambia; GNB : Guinea Bissau; LBR : Liberia ; MLI : Mali ; MRT : Mauritania ; NER : Niger; NGA : Nigeria; SEN : Sénégal; SLE: Sierra Leone; TCD: Tchad; TGO: Togo

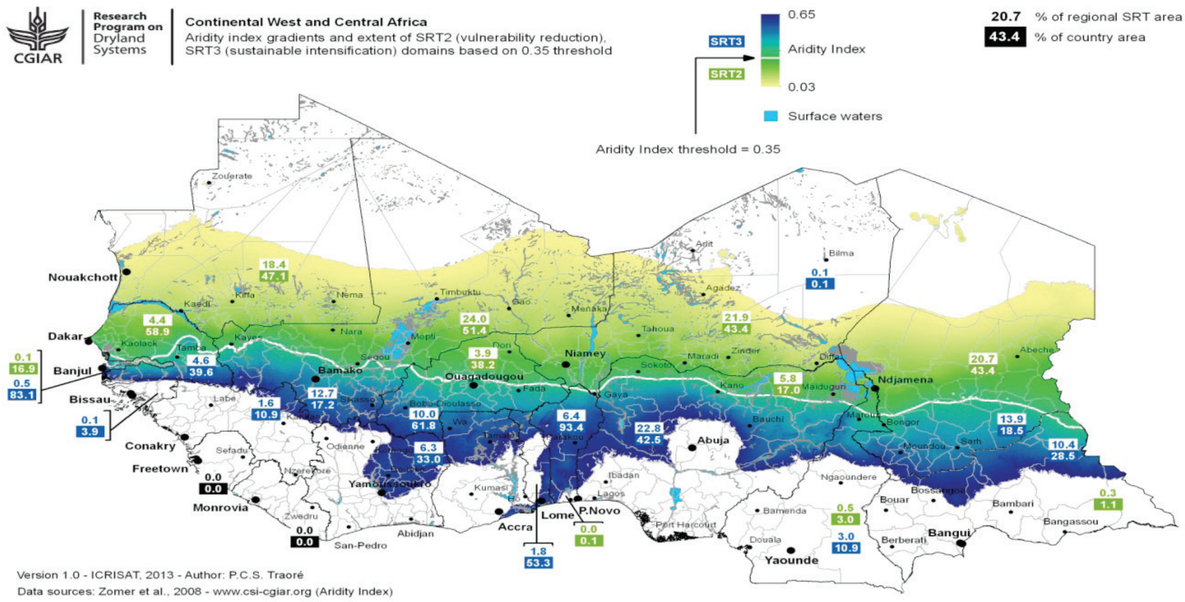

Figure 3a

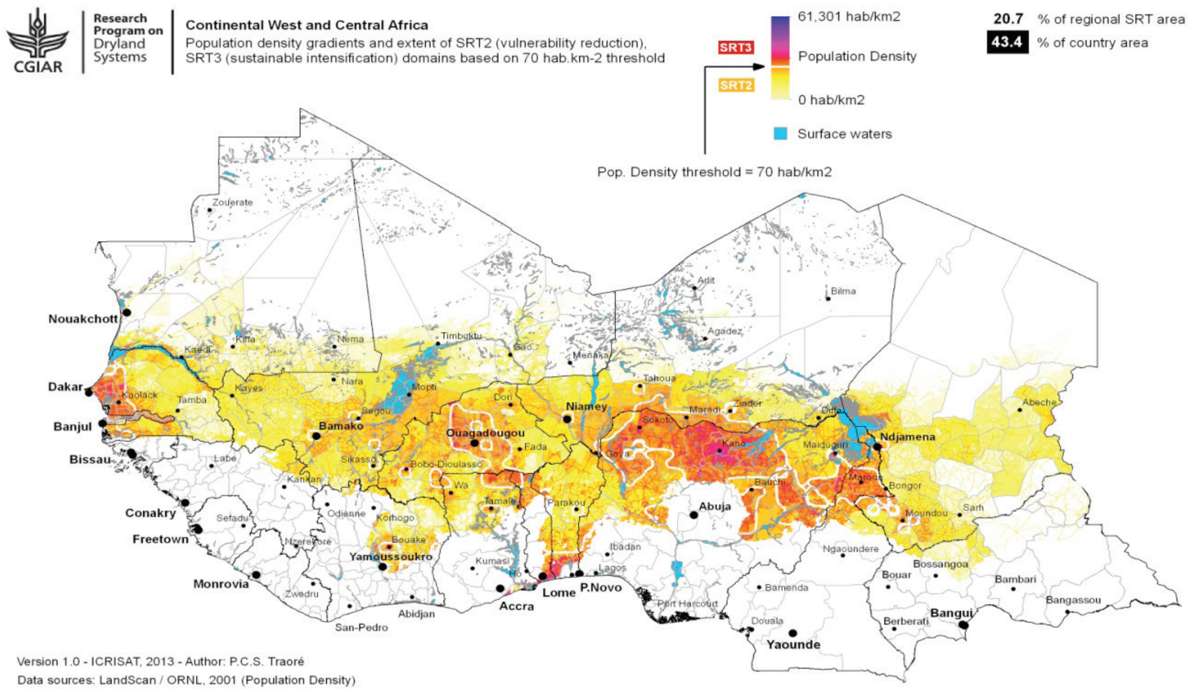

Figure 3b

Figure 3: Continental West and Central Africa. Extent of SRT2 (vulnerability reduction), SRT3 (sustainable intensification) domains as defined by (a) aridity and (b) population gradients. Threshold values: 0.35 (aridity index), 70 hab.km^{-2} (population density).

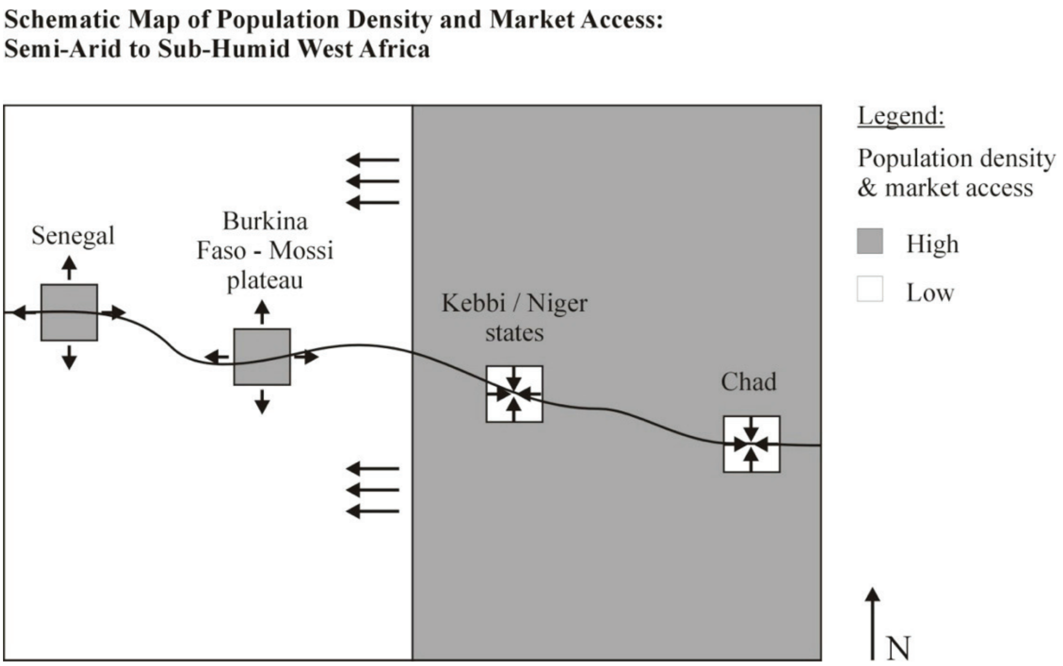

Figure 4 (a)

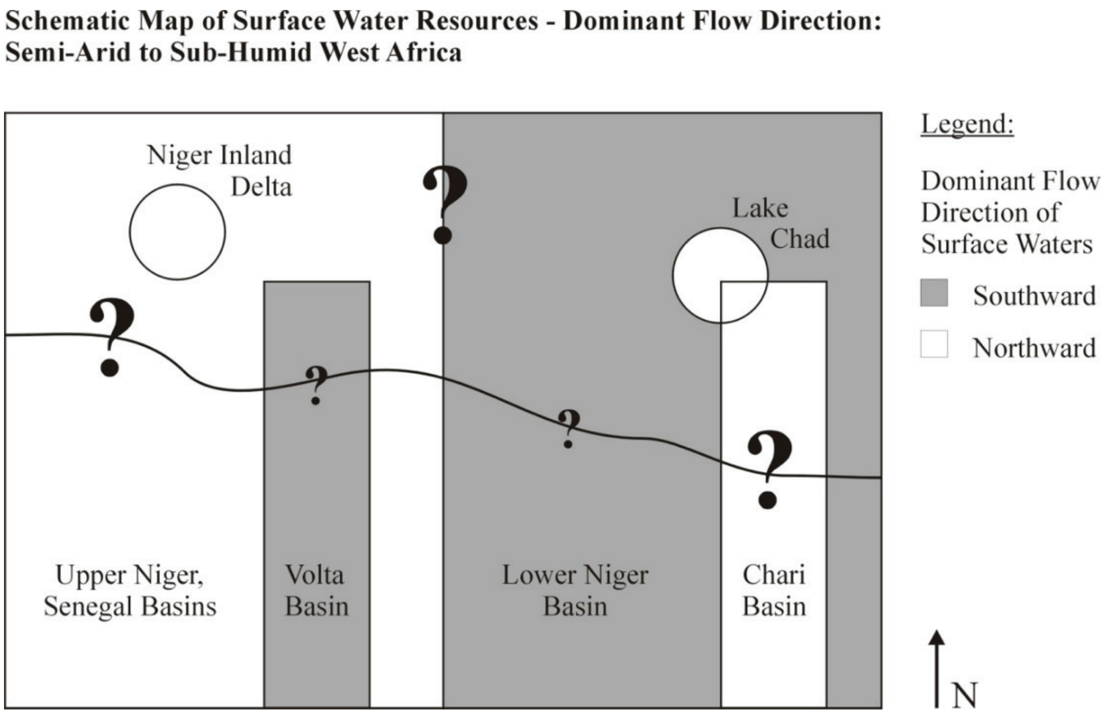

Figure 4 (b)

Figure 4: Schematic maps of (a) population density and market access, (b) surface water resources (dominant flow direction) for West Africa's drylands. The east-west bisecting curve schematizes the limit between SRT2 and SRT3 domains as defined by the 0.35 aridity index threshold.

Table 4: Aridity index (AI) and population density (PD) metrics for pre-selected *Dryland Systems* countries (Burkina Faso, Mali, Niger, Nigeria) plus Ghana, Senegal and the whole Drylands domain. For each metric, statistics include number of pixels considered (count), minimum value, maximum value, sum (except AI), mean, standard deviation, and natural break point (Jenks, 1967). Metrics for population density include a truncated histogram for]20;200[interval to eliminate effect of extreme (empty, urban) area values on breakpoint calculation

Country Metric	BFA	GHA	MLI	NER	NGA	SEN	Dryland Systems
AIcount	328,908	116,815	1,040,013	710,828	644,910	233,215	5,258,829
AImin	0.142	0.428	0.003	0.003	0.117	0.092	0.003
AImax	0.640	0.650	0.650	0.440	0.650	0.650	0.650
AImean	0.383	0.577	0.214	0.119	0.443	0.326	0.281
AIstdeve	0.113	0.043	0.174	0.069	0.142	0.139	0.204
AIbreakpoint (2 strata)	0.375	0.576	0.274	0.134	0.424	0.351	0.310
PDcount	328,908	116,803	1,040,185	710,506	644,904	233,110	5,253,663
PDmin	0	0	0	0	0	0	0
PDmax	19,505	45,381	23,930	41,556	41,797	32,975	61,302
PDsum	12,279,374	6,840,108	10,975,805	10,351,374	49,692,527	9,670,122	126,464,849
PDmean	37	59	11	15	77	41	24
PDstdev	174	682	129	171	459	454	270
PDbreakpoint (2 strata)	725	10,816	5,430	10,034	6,568	8,472	9,137
PDcount]20;200[	116,003	34,954	96,393	110,693	438,259	66,326	1,067,949
PDmin]20;200[	20	20	20	20	20	20	20
PDmax]20;200[	200	200	200	200	200	200	200
PDsum]20;200[	4,539,799	1,408,669	3,237,104	3,519,118	22,702,285	3,197,364	48,535,115
PDmean]20;200[	39	40	34	32	52	48	45
PDstdev]20;200[	25	29	20	20	34	34	32
PDbreakpoint]20;200[(2 strata)	67	71	55	64	76	72	72

gradients are a potent proxy for the primary change induction factor that will affect agricultural systems: population growth. In West Africa, enormous longitudinal variability in population density, production systems and market access, and the regional liberalization of exchange and trade can explain highly contrasting situations within single agro-ecology (e.g. variations in biotic pressures). It should therefore play a primary role in discretizing the continuum of highly vulnerable to intensifying conditions. Indeed, wherever relative biophysical homogeneity and low determinism prevail, the spatial distribution of SRT2 and SRT3 conditions is more likely to be controlled by socio-economic than biophysical drivers. System intensification, defined as the substitution of labor for land, is most consistently associated with high rural population densities (Stone 1994).

Socio-economic factors express biophysically: At the regional scale already, SRT2 and SRT3 conditions are intricately intertwined. Assuming the two conditions were disjoint and aridity index was a good predictor thereof, Figure 4b shows that SRT2 areas may be at a risk of higher vulnerability when SRT3 areas need to secure more resources to sustain their own growth and intensification. Indeed, improved water harvesting in higher catchments (SRT3 areas in northbound flowing river systems) will threaten the sustainability of surface (and possibly ground) water supply in lower SRT2 catchments. Likewise, observed and expected faster population growth in the transition Sudanian agro-ecological zone (here SRT3) may seal off N-S raw nutrient resource flows through a reduction of long-distance transhumance.

Selecting sites that trade space for time: For these reasons, *Dryland Systems* research questions, hypotheses, and sites in West Africa should therefore be directed E-W as much as N-S: along population density gradients as much as across agro-ecological zones, as under higher population densities, lateral raw resource flows may decrease (Figure 7). We expect that the complementarity between action transects will help 'ground' the *Dryland Systems* conceptual framework into the physical action-research space. In addition to larger geographical representativeness, action transects present several advantages over spatially disjoint and assumingly homogeneous action sites to sample the SRT2 to SRT3 continuum: they provide a geographically contiguous frame to understand the complementarities and forms of integration between the two target systems. Space can often be traded for time to visualize future systems evolution and opportunities, as in Nigeria's Plateau State faithful Boserupian intensification from crowded areas to empty and then crowding frontiers (Stone 1992). *Dryland Systems* recognizes that interactions between the two zones (market innovation, or resource management, employment/diversification, among others) can also lead to innovations with potentially widespread applicability. Geographical proximity makes it easier to demonstrate this in the real world, for example through farmer exchange visits.

Representativeness of selected sites: Transect (distance) sampling is a popular method in ecological science to efficiently estimate the density of biological populations and relate it to topographical, environmental, habitat, and other spatial gradients in conditions where survey designs cannot be randomized and/or stratified. Conceptually, the same approach can be applied to the agro-ecological sub-domain to estimate the density of human populations, domestic animals, cropping systems, and relate them to a continuum of biophysical and socio-economic conditions that intimately affects the agricultural intensification and vulnerability reduction potentials. As expected, the KKM and WBS transects proved to sample a larger variability of aridity and population density conditions relative to compact shapes or administrative units of similar areas.

Our initial expectation that WBS would cover a wider variation of population densities than KKM proved false, but is partially an artifact of KKM reaching far into quasi-desertic, unpopulated areas (north of Maradi region cutting deep into the low-low [AIxPD] zone: green area on Figure 5). In practice, the KKM transect does not reach into that low-low zone, which is only included here to yield transects of equivalent area for comparative purposes. WBS does contrastingly cover a much larger diversity of dominant language clusters (Figure 6). As population density varies over much shorter distances than the aridity gradient, transect aridity ranges control most of the extent of their dissemination domains (or representative areas) on a regional scale.

Site selection impacts R4D outcomes: Geographical targeting in research projects often results from expert consultations where existing partnerships, infrastructure and political considerations rank high among selection criteria, making the process susceptible, *inter alia*, to snowball sampling bias and subsequent shoehorning of R4D activities. One way to avoid such shortcomings is to ensure expert consultations are inclusive and participatory. Another is to provide a quantitatively and conceptually sound, data-rich framework on regional determinants of change. We recognize that the limited availability of spatially continuous and granular GIS data for many targeting criteria restricts their consistent use as a prognostic tool for site selection. Yet it is important to remain aware of potential biases arising from partners' own disciplinary legacy, and to monitor contextual relevance across all scales of investigation. For example, Table 1 misses proximity to surface waters for irrigation use, which is important in West African and other drylands, not only at the local scale but also on a much larger regional level (Figure 4b).

Conclusion

Beyond limitations arising from variable granularity in available GIS data and from scale mismatches between underlying natural and anthropic processes, it appears that poverty levels in West Africa are not any more dependent upon latitude than longitude, and vice versa. As such, documented poverty levels can hardly inform the selection of *Dryland Systems* sites and spatial targeting relies on aridity and population density as the two minimum biophysical and socio-economic determinants of vulnerability reduction and agricultural intensification potential. There is an obvious large-scale latitudinal association between aridity index and population density (as deserts are always loosely populated), yet the aridity index can only explain 2% of the fine scale variation in population density across the region. A very significant variation occurs longitudinally as well, as entire swaths of the Sahel remain largely devoid of population, while others are already mutating fast into megalopolises of the future (Raynaut 2001).

In fact, the transcription over space of civilizations and history results in complex spatial patterns that are not always controlled by simple environmental determinisms. In the West African dryland hinterland, a mostly flat region characterized by a shallow, latitudinal climatic gradient, the Sahel ecotone has proven most hospitable for human societies, often yielding above average rural population densities and city sizes, and a recent spillover trend towards the sub-humid drylands driven essentially by land availability. Kano, the third largest West African city by population (after Lagos and Abidjan) and its multi-million satellites of Kaduna, Katsina, Zaria is by far the number one conurbation of the West African drylands. It draws from and caters to a highly intensified production hinterland that provides today invaluable examples of what other areas of

Table 5: Amount of variability in aridity and population sampled by generic and administrative bounding shapes of different compactness but roughly equal areas

Sampling case	Sample Description	Sample area (km^2)	Variation in population density sampled[1]				Variation in aridity index sampled			
			Mean	Stdev	% change (vs. circle)	% change (vs. compact)	Mean	Stdev	% change (vs. circle)	%change (vs. compact)
Entire population	West African drylands	4,352,006	13.8	22.29			0.28	0.203		
Large sub-national region sample	Circle, 160-pixel radius[2]	80,384		14.05	0.00			0.051	0.00	
	Square, 283x283 pixels[1]	80,089		14.10	0.35			0.052	1.93	
	North-South transect, 200x400 pixels[1]	80,000		14.66	4.34			0.071	38.41	
	East-West transect, 400x200 pixels[1]	80,000		13.90	-1.06			0.041	-20.06	
	WBS compact area equivalent[3]	70,384	14.3	16.37	16.51	0.00	0.60	0.038	-26.04	0.00
	KKM compact area equivalent[4]	79,017	15.3	13.05	-7.13	0.00	0.22	0.044	-13.29	0.00
	WBS large transect[5]	84,615	18.1	18.09	28.72	10.48	0.51	0.046	-9.59	22.23
	KKM large transect[6]	83,115	52.8	44.85	219.16	243.67	0.30	0.136	166.70	207.59
Smaller district-level sample	Circle, 36-pixel radius[1]	4,069		11.06	0.00			0.012	0.00	
	Square, 64x64 pixels[1]	4,096		11.14	0.65			0.013	2.69	
	North-South transect, 45x91 pixels[1]	4,095		11.27	1.84			0.017	33.06	
	East-West transect, 91x45 pixels[1]	4,095		11.17	0.96			0.011	-12.34	
	WBS compact area equivalent[7]	4,204	9.1	14.59	31.90	0.00	0.54	0.015	16.99	0.00
	KKM compact area equivalent[8]	3,360	22.2	6.62		0.00	0.16	0.015	19.71	0.00
	WBS small sub-transect[9]	4,740	23.3	10.65	-3.74	-27.02	0.50	0.028	121.25	89.12
	KKM small sub-transect[10]	3,242	56.3	37.41	238.10	465.45	0.28	0.111	789.98	643.46

[1]For the]20;200] hab.km-2 range to exclude desertic and highly urbanized areas (source: LandScan, 2001 data); [2]For generic shapes (circle, square, North-South and East-West transects), reported standard deviations are average standard deviations computed across moving windows covering the entire extent of the West African drylands; [3]Northern Region, Ghana; [4]Mopti Region, Mali; [5]Upper West Region + [Kenedougou + Houet + Bougouriba + Ioba + Tuy + Banwa] Provinces + [Koutiala + Sikasso + Yorosso] Districts; [6]Maradi Region + [Katsina + Kano] States; [7]Sissala East District, Ghana; [8]Mayahi department, Niger; [9]Lawra-Jirapa Districts + Samoghohiri Department + Molobala Commune; [10]Aguie Department + [Zango Daura + Bebeji] LGAs

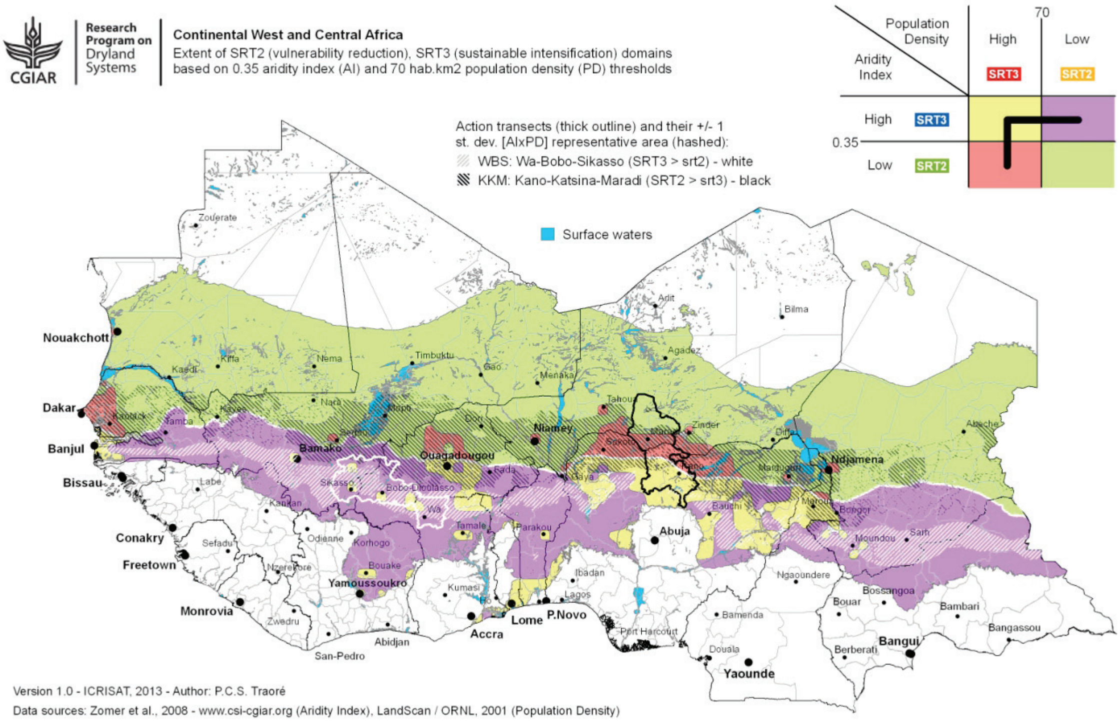

Figure 5: Continental West and Central Africa. Extend of compound SRT2-to-SRT3 domains as defined by the 0.35 aridity index and by the 70 hab.km^{-2} population density thresholds, with the Kano-Katsina-Maradi (KKM) and Wa-Bobo-Sikasso (WBS) large transects overlaid (thick outlines). Representative areas for each transect are hashed and correspond to values of aridity (AI) and population (PD) comprised within ±1 standard deviation from each transect mean.

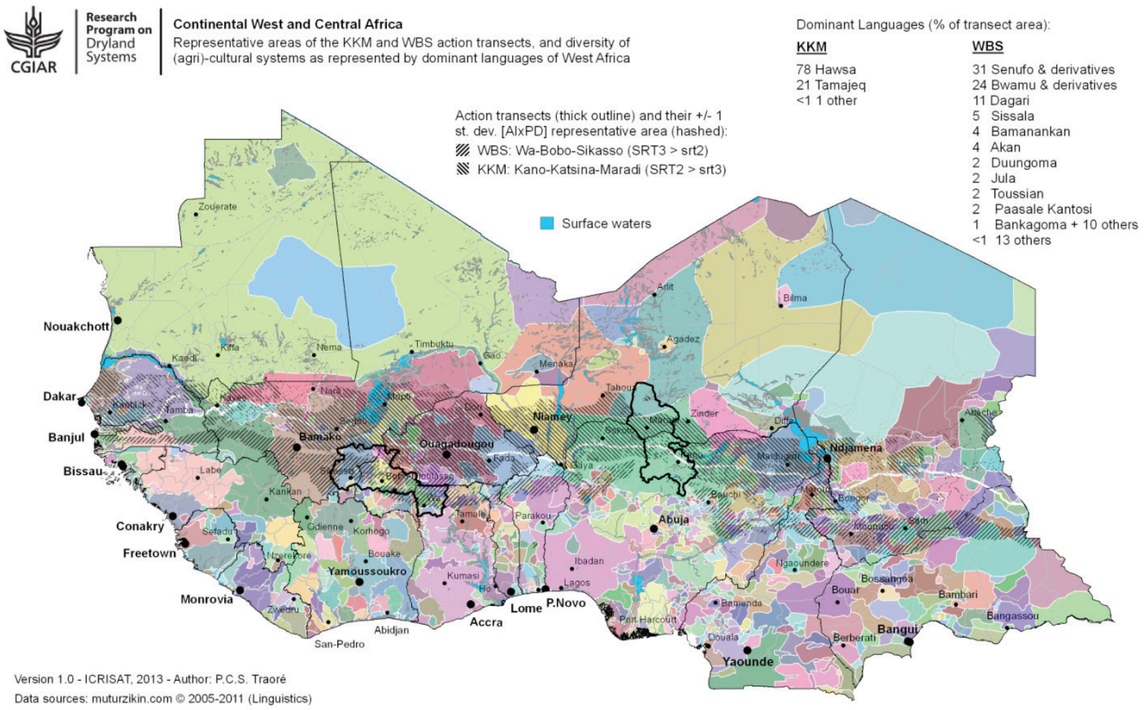

Figure 6: Continental West and Central Africa. Representative areas of the KKM and WBS action transects, and diversity of (agri)-cultural systems as represented by dominant languages of West Africa. The percent area occupied by each intersected dominant language cluster highlights a tenfold increase in linguistic diversity from the KKM to the WBS transect.

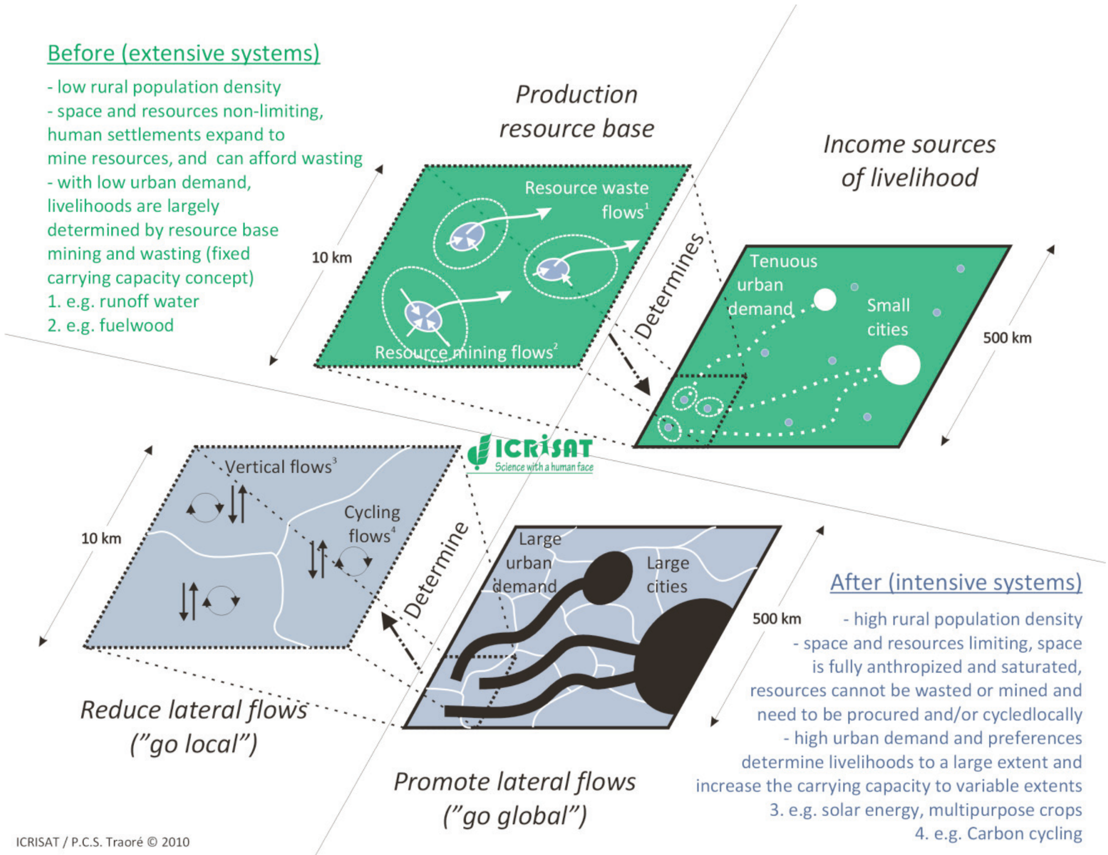

Figure 7: Schematic spatial representation of systems change from extensive, determined by the resource base (before) to intensive, determined by the urban demand (after).

the region may look like tomorrow. High population densities can result in sustainable, intensive farming systems (Harris 1996).

The two contrasted West African action transects proposed for *Dryland Systems*: KKM and WBS sample a larger biophysical and socio-economic variation than any administrative unit of comparable area in West Africa. As such, we believe that they are more agile at capturing the scale-dependent SRT2-SRT3 continuum, with a significant complementarity between an already highly populated and intensified KKM where focus should consequently be on vulnerability reduction, and a sparsely populated and extensive WBS where agricultural intensification should, conversely, receive priority. These contrasted biophysical, socio-economic, and historical R4D settings may be particularly conducive to: i/ concurrent within-transect dissemination and uptake of dominantly process-based interventions in a culturally homogeneous area (KKM), and dominantly technology-based interventions in an ecologically homogeneous area (WBS); ii/ sequential between-transect transfer of knowledge, intensification shortcuts as population growth and urbanization drives the WBS transect and comparable regions through land tension thresholds, tipping points in available resource, and agricultural systems change similar to those earlier experienced in KKM.

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Dryland Systems' action research agenda to mitigate problems of drylands in Central Asia and the Caucasus

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Extended abstract

The Soviet-era development of irrigation in the Amu Darya and Syr Darya basins has caused irreversible damage to the environment around the Aral Sea: drying-up of the Aral Sea, waterlogging and salinization of agricultural and pasture lands, disappearance of fishing industry, over-grazing of range lands, deforestation, etc. With the consequent low productivity of agricultural, pasture and range lands, the lives of the farmers and ranchers are significantly impacted. Climate variability, drought and extreme heat and cold stress exacerbate the situation there. Similarly, agriculture and livestock production people in mountainous areas of Tajikistan and Kyrgyzstan are suffering from low productivity because of short growing season, poor irrigation infrastructure and accessibility to agricultural inputs and markets, bartered economy, etc. Conversely, there are areas, such as the Fergana Valley, where irrigated agriculture is very productive. However, due to high population density, lack of crop rotation, climate change, inadequate market conditions, sustaining the profitability of irrigated agriculture is at risk there.

The dryland systems are very complex by nature. The CGIAR Dryland Systems CRP Team in Central Asia and the Caucasus (CAC) region used a participatory and multidisciplinary approach in selecting research sites and defining the research agenda for the region. In July of 2011, a team of CGIAR scientists and NARS from the CAC countries participated in the Inception Workshop held in Nairobi, to select the research sites. Three action sites and two satellite sites were identified for CAC region. Under theme SRT2 (*Reducing vulnerability and managing risk*) two action sites were selected: Rasht and Kyzyl-Suu Valley of Tajikistan and Kyrgyzstan, and an area adjacent to the Aral Sea in the countries of Kazakhstan, Turkmenistan and Uzbekistan. A site in Azerbaijan was selected as a satellite site. Under SRT3 (*Sustainable intensification for more productive and profitable dryland agriculture*), only one action site covering Fergana Valley and one satellite site in the Province of Kashka Darya, Uzbekistan were selected.

In a workshop held in Tashkent in a pre-stakeholder workshop in May, 2012, NARS, researchers from the CGIAR and non-CGIAR (ICBA and AVRDC) centers, and the German Center for Development Research (ZEF) deliberated on the action research topics and agreed upon a set of research hypotheses. The proceedings were distributed to the stakeholders for review and discussed during the Dryland Systems Stakeholders workshop in Tashkent in June, 2012. The action research topics were debated in separate groups, one for each action site, and a set of interdisciplinary research topics were identified. The topics include: use of non-conventional water for irrigation, adoption of small-scale irrigation technologies; crop diversification to adapt to soil salinity, heat and drought; strengthening mixed cropping systems of cereal, legume, and vegetable crops; market value chain analysis of commodities to improve small-scale farmers' access to markets; IT for knowledge dissemination on water and land productivity; and impacts of climate change on water availability, water productivity and livelihoods of farmers.

Concurrent Session Presentations

Theme 1, 2 and 3
Food and energy security in drylands – Challenges triggered by global changes; Role of dryland agriculture in mitigating strategies for climate change; Global climate change and its impact on different dryland ecosystems

Halophytic plants (environmentally smart crops) for forage, biofuel production and soil bioremediation.

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Abstract

Leptochloa fusca, *Kochia indica*, *Sporobolus virginicus*, *Salicornia europaea* and *Spartina patensare* highly salt tolerant C_4 halophytic forage plants grow well in coastal salt marsh. They have a special place in newly emerging farming systems, especially in coastal areas and where freshwater resources are not available or are in short supply. Growing halophytic plants as a multi-use crop for forage and biofuel production on salt affected land that can be irrigated with brackish water or seawater, can spare fresh water and high quality soil for food and feed production while bringing poor land into cultivation. Field trials were carried out in salt affected soil around the coast of Qaron Lake to evaluate the impact of irrigation with 2500 ppm salt loaded drainage water on the productivity and the nutritional value of these forage plants as well as the possibility of using them for biofuel production and bioremediation of the salt affected soil. All tested plants tolerated harvesting ten times per year and were capable of recovering and maintaining a fresh productive biomass of 8.42 to 15.88 ton ha^{-1}. The crude protein varied between 8.32 and 10.2 %. The cellulose and hemicelluloses concentration being between 25.14 and 31.23%, these plants can be used for ethanol production. Successive harvest improve soil quality by decreasing SAR and electrical conductivity of the soil as some of these plants can accumulate salts in vacuoles in their leaf cells. *Leptochloa fusca* followed with *Sparina patents* were most effective for soil bio-reclamation. Thus these halophytic plants can be called "environmentally smart crops".

Introduction

The world's population is expected to reach 9 billion in 2050 (United Nation 2013). This increase, together with accelerating urbanization, water scarcity, desertification and the negative impact of climate changes on fresh water resources, will exert increasing pressure for food, forage and fuel demand and critically undermine efforts for sustainable development (IPCC 2007). With current climate warming and increased evapotranspiration, global salinization will steadily continue (Rozema and Flowers 2008). Moreover, currently at least 97% of the global water is seawater, 20 % of the world's irrigated land is salt affected and/or irrigated with waters containing elevated levels of salts (ICBA 2010). Therefore, an integrated approach for solutions is required through economic, social and environmentally sustainable developmental **(**Koyro *et al*. 2011**)**. Cultivation of halophytic plants seems to be an ideal management practice for such situation, when fresh water is not sufficient (González *et al*. 2005).

Halophytic forage plants are highly salt tolerant plants growing well in coastal salt marsh (Tawfik *et al*.,2011). They have a special place in newly emerging farming systems, especially in coastal areas and where freshwater resources are not available or in short supply. They are environmentally smart crops because they can ensure food security, contribute to energy security, guarantee environmental sustainability, tolerate the impacts of climate change (water stress, salt stress and high temperatures), increase livelihood options, sequester CO_2 and bio-remediate salt affected soil (FAO 2010). Growing these plants can increase sustainable productivity, strengthen farmers' resilience, reduce greenhouse gas emissions from agriculture and cause transformation of agriculture in the way we grow food, feed and biofuel and treat the environment. Freeing fresh water and high quality soil for food and feed and bringing poor land into production can add to feed and food security (Tawfik *et al*. 2013). A wealth of halophytic flora exists which can be exploited for an array of uses like food, forage, fodder, fuel wood, oilseed, medicines, chemicals, landscaping, ornamentals, and environment conservation through carbon sequestration (Khan *et al*. 2006).

Bioenergy crops are crops capable of producing renewable energy from materials derived from biological sources. Many different perennial and annual halophytic plants, including oil producing crops and crops as sources of lignocellulosic biomass, can be included under this group (Wright 2006). However, a drawback to conventional biofuel crops is that they require the diversion of farmland, pastures, and rangelands from food to fuel production. That is why saline agriculture, an undeveloped source for both food and fuel, is so interesting (Hendrick and Bushnell 2008). A promising avenue is thus the production of biofuels from halophytes (Xianzhao *et al*. 2013), as they can be produced on land that is not suitable for conventional agriculture.

The Egyptian flora comprises about 2300 species of which 80 are halophytic, belonging to 32 genera and 17 families (Batanouny 1994). They include some perennial grasses that are recommended as forage, fodder and biofuel crops. These plants are abundant in nature, are outside the human food chain, and require low maintenance which makes them relatively inexpensive to grow. Flowers and Yeo (1995) have advocated that it is perhaps cheaper, easier and, may be, more successful to domesticate a wild salt-tolerant species than modify an existing crop to get gainful returns from a saline environment. The aim of this paper is to discuss domestication of these halophytic plants and to evaluate their potential for producing biomass for forage, fuel and soil bio-remediation in the salt affected habitats.

Materials & methods

Field trial was conducted during 2012 summer season on a salt affected farm on the Coast of Qaroun Lake to study the effect of irrigation with 2500 ppm salt affected drainage water on fresh biomass production, some physiological aspects, nutritional value, and cellulose, hemicelluloses and lignin content of five halophytic plants namely *Leptochloa fusca*, *Kochia indica*, *Sporobolus virginicus*, *Salicornia europaea* and *Spartina patensare*, as well as studying the effect of the successive cuttings of these plants on soil bio-remediation. Chemical analysis of irrigation water showed that its pH was 7.88, EC was 6.55 ds/m, and the concentration of Na 1236.5 mg/L, K 54.3mg/L, Cl 2154.3mg/L) and Mg 29.65mg/L.

Each plant species was transplanted on 7 May 2012 in five 4 m^2plots. The mechanical and chemical analysis of the soil (Table 2) was carried before the experiment and after three cuttings using the standard method described by Klute (1986).

Three equal doses of single superphosphate (15.5% P_2O_5), potassium fertilizer (48.0 % K_2O) and urea (46.5% N) were applied at the rate of 32 kg P_20_5/fed., 24 kg K_2O/fed and 105 kg N/fed, respectively, after each of the three cuttings taken at 45 days intervals. Three replicates of each treatment were used to determine fresh weight. The following physiochemical measurements were determined in the fresh harvested shoot of the second cutting: chlorophyll a+b (mg/g fresh weight) according to Von Wettstein (1957), proline (µg/g) according to Bates *et al*. (1979), osmotic potential obtained from the cell sap concentration tables given by Gusev (1960). Then the harvested shoots were dried to constant weight at 70° and the values of succulence (ratio of fresh weight/dry weight) were calculated according to Tiku (1975). Soluble carbohydrates content was also determined by the method described by Dubois *et al*. (1956). The contents of sodium and potassium were determined in the digested material using Jenway Flame Photometer as described by Eppendrof and Hing (1970). Calcium was determined according to Jackson (1967). K/Na, Ca/Na ratio was also calculated for each treatment. Crude protein (CP), crude fiber (CF), ether extract (EE) and ash were determined by standard analytical methods after AOAC (2005). Nitrogen free extract (NFE) was calculated by the following formula: % NFE = 100 - (%CP + %CF + %EE + %ash). ADF and NDF were determined after Komarek (1993). The ligno-cellulosic biomass analysis is related to plant fiber estimation. We used the method of AOAC (2005) involving multifunction process for the separation of cellulose, hemi-cellulose and lignin from the other constituents of ligno-cellulosic biomass. The obtained results were subjected to statistical analysis of variance according to Snedecor and Cochran (1982).

Results & discussions

Effect of halophyte planting on the physical and chemical properties of soil

Soil analysis before transplantation and after 135 days from growing of *L fusca., K inica, S virgincus, S europeae and S, patens* are shown in (Table 1). The values of Mg, K, organic C and percentage of silt were slightly increased after three harvests of these halophytic plants, whereas Ec, HCO_3, SO_4, Cl, Ca, Na and percentage of sand decreased by the end of the experiment with superiority of *L fusca*. However, pH and clay content were not affected. These results are in agreement with those obtained by Tawfik *et al*. (2013). Zaharan *et al*. (1982) observed that *Juncus rigidus* decreased the soil EC from 33 to 22 dS m^{-1}. Singh *et al*. (1989), in a long-term field study on improving an alkaline soil by growing *Prosopis julifera* and *Leptochloa fusca,* found that the soil EC decreased from 2.20 to 0.42 dS m^{-1}. Akhter *et al*. (2004) stated that kallar grass (*Leptochloa fusca*) accomplished the best removal of salts but had very little beneficial effect on pH and SAR. Ravindran *et al*. (2007) hypothesized that beneficial effects of plants in reclamation are not well understood but appear to be related to the physical action of the plant roots, addition of organic matter, increase in dissolution of $CaCO_3$ and mobilization of calcium that helps reclaim soil sodicity and crop uptake of salts. They added that *Suaeda maritima* and

Table 1: Effect of halophyte planting on the physical and chemical properties of soil

Soil characters	Before transplantation	After three cuttings of growing halophytes (135 days from transplantation)				
		L. fusca	*K. indica*	S. virginicus	S. europeae	S. patens
Ec (m mohs/cm)	15.36	12.98	13.88	13.68	15.03	14.12
HCO3%	13.25	12.68	13.13	12.98	12.89	13.02
SO4%	80.47	72.36	74.23	75.26	77.36	73.68
Cl%	199.54	187.26	187.72	190.15	193.65	189.45
Ca (ppm)	78.58	75.69	75.12	76.12	77.98	75.69
Mg (ppm)	27.69	28.55	28.03	28.13	28.14	27.98
K (ppm)	1.89	1.98	1.95	1.95	1.94	1.91
Na (ppm)	299.68	277.91	279.9	283.05	288.54	281.95
pH	7.45	7.41	7.42	7.47	7.45	7.44
Organic C	2.15	2.48	2.44	2.58	2.59	2.39
Sand	22.36	22.02	22.12	21.98	21.86	21.88
Silt	16.25	16.55	16.33	16.12	16.54	16.03
Clay	61.39	61.43	61.55	61.9	61.6	62.09

Sesuvium portulacastrum exhibited greater accumulation of salts in their tissues as well as higher reduction of salts in the soil medium. Ahmed (2010) stated that *Leptochloa fusca* behaved as a typical halophyte having both salt accumulating and excreting properties. He added that, the efficient salt excretion from the shoot makes it a useful plant to deplete excessive salt from the root zone and to provide a better root environment for the growth of other plants. Growing this plant increased air exchange, organic matter and hydraulic conductivity, decreased rhizosphere pH, stimulated biological activity, dissolved native $CaCO_3$, enhanced leaching of salts, lowered the water table of waterlogged soils, released plant nutrients and the shoot foliage could increase organic matter, humus and soil mulch, decrease surface evaporation and progressively improve soil physical properties. In our experiment, the halophytic grass *L. fusca., K. inica, S. virgincus, S. europeae and S. patens* were very useful with *L fusca* being superior to others.

Fresh and dry weight for three cuttings of different halophytic plants

Data presented in Tables 2 and 3 show total productivity of the tested halophytes. Significant differences were obtained between different plant species with superiority of *L. fusca,* which recorded the highest fresh and dry weight. All plant species behaved like true halophytes (highly tolerant of salinity). Similar results were obtained by Akhter *et al.*(2004) who reported that low NaCl concentrations stimulated growth of some halophytic species. Such effect may be attributed to improved shoot osmotic status as a result of increased ions uptake metabolism (Naidoo *et al.* 1995). Abdal (2009) reported yield of *S. bigelovii* of 11 Tons/ha under seawater irrigation in sandy soils of coastal areas in Kuwait. Similar results were obtained by Tawfik *et al.* (2011) who reported that low NaCl concentrations stimulate biomass productivity of *Sporobolus virginicus*. In the present study, medium concentrations of saline irrigation promoted fresh biomass productivity.

Table 2: Fresh and dry weight for 3 cuttings of different halophytes (kg/m^2)

Halophytic plant species	First cutting		Second cutting		Third cutting		Total productivity of three cuttings/m^2	
	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
L. fusca	0.514	0.162	0.555	0.154	0.520	0.147	1.588	0.464
K. indica	0.455	0.134	0.535	0.147	0.475	0.127	1.465	0.408
S. virginicus	0.417	0.120	0.481	0.133	0.424	0.114	1.322	0.367
S. europeae	0.266	0.056	0.295	0.057	0.281	0.060	0.842	0.172
S. patens	0.400	0.120	0.457	0.120	0.411	0.114	1.268	0.355
LSD 5%	0.033	0.019	0.029	0.018	0.031	0.017	0.078	0.036

Table 3 : Fresh and dry weight for 3 cuttings of different halophytes (Ton/ha)

Halophytic plant species	First cutting		Second cutting		Third cutting		Total productivity of three cuttings/h	
	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
L. fusca	5.136	1.619	5.546	1.545	5.195	1.474	15.878	4.638
K. indica	4.554	1.341	5.348	1.471	4.746	1.270	14.648	4.082
S. virginicus	4.175	1.202	4.807	1.328	4.238	1.139	13.219	3.669
S. europeae	2.660	0.557	2.950	0.569	2.810	0.596	8.420	1.722
S. patens	4.004	1.202	4.567	1.202	4.111	1.145	12.682	3.548
LSD 5%	0.321	0.063	0.423	0.063	0.421	0.069	1.023	0.301

Similar performances were also found by Qi *et al*. (2005) and Li *et al*. (2006) who found that the growth of *Suaeda salsa* increased significantly with NaCl concentrations when exposed to hyposaline environment.

Biochemical composition and physiological attributes

Data (Table 4) show significant variations in the studied parameters in different plant species. The highest values of Chl. a+b and K as well as the ratio of both K/Na and Ca/Na were recorded in *L. fusca*, whereas the highest values of soluble carbohydrates, proline, Na, Ca, succulence and osmotic potential were recorded in *S europeae.* Similar results were obtained by Youssef (2009). Youssef and Al-Fredan (2008) suggested that under high salt stress plant cells decrease their osmotic potential by accumulation of some solutes such as proline and soluble sugars. The accumulated sugars, in addition to the role of regulating osmotic balance, also act as the metabolic signals in the stress conditions (Munns and Tester 2008). Proline shows an indirect protective function due to its antioxidant properties in addition to the direct effect to stabilize the macro-molecules and their hydration layers (Bohnert *et al*. 2004). Murphy *et al.* (2003) suggested that both proline and soluble carbohydrates act as compatible solutes under high salinity levels. Kusaka *et al.* (2005) added that the observed increase in the osmotic potential might be due to the accumulation of inorganic solutes, several organic components such as sucrose, glucose, quaternary ammonium compounds, and amino acids including proline. Munns (2003) proved that, higher concentrations of carbohydrates in response to salinity are probably due to reduced growth. He added that, excessive sodium ions at the root surface disrupt plant potassium nutrition. In our study proline and soluble sugars content increased significantly in the leaves of all plant species as the salt concentration increased. Osmotic adjustment by accumulation of osmolytes is an important adaptation of halophytes to counter physiological drought imposed by salinity (Flowers and Colmer 2008). Halophytes are reported to accumulate organic osmolytes such as proline, glycinebetaine and sugars mainly in cytoplasm for osmotic adjustment without impairing metabolic activities (Debez *et al*. 2010). Accumulation of these organic osmolytes in cytoplasm compartmentalization in the vacuole contributes significantly in overall improved water relations of halophytes on saline soils.

Table 4: Biochemical composition and some physiological attributes of the tested halophytic plant species

Characters	**Halophytic plant species**					**LSD**
	L fusca	***K idnica***	***S virgincus***	***S europeae***	***S patens***	**(5 %)**
Chlorophyll a+b (mg/g dry wt.)	6.44	5.71	5.68	6.02	5.36	0.18
Soluble carbohydrates %	42.33	43.25	43.15	46.36	45.26	2.36
Proline (ug/g dry wt.)	444.58	412.35	465.34	521.36	484.55	25.36
Potassium content (mg/g dry wt.)	10.92	10.25	10.87	9.36	10.27	0.62
Sodium content (mg/g dry wt.)	10.55	10.85	11.14	13.25	12.07	0.65
Calcium content (mg/g dry wt.)	3.41	3.45	3.49	4.12	3.74	0.29
K/Na ratio	1.04	0.94	0.98	0.71	0.85	0.95
Ca / Na ratio	0.32	0.32	0.31	0.31	0.31	0.45
Succulence (fresh wt./dry wt.)	3.42	3.58	3.60	4.89	3.89	3.57
Osmotic potential	9.23	9.35	9.87	10.32	9.58	1.25

Nutritional values of the tested halophytic plants species

Current knowledge of the nutritive value of halophytic plants in Egypt is limited. Data in Table 5 showed that *L fusca., K inica, S virgincus, S europeae and S, patens* contained moderate amounts of crude protein (CP) which is fair enough to cover the nitrogen requirements of grazing animals. They also contained high levels of fiber and ash contents, which could limit intake, and digestibility of such forages. Similar results were obtained by (El Shaer *et al*.2004). Ether extract (EE), nitrogen free extract (NFE), acid detergent fiber (ADF) and neutral detergent fiber (NDF) varied considerably among the different species. The highest values for NDF, EE and NFE were recorded in *L. fusca*, while the highest value CP was recorded in *S. virginicus*. On the other hand, the highest values for ADF, CF and ash were recorded in *S. patens*, *S. europeae* and

K. indica respectively. It is reported that fibrous materials and ash contents of halophytic feed materials are higher and increase while gross energy and protein contents are low and decrease with advancing maturity (Kandil and El Shaer, 1988). Based on data in Table 5, it seems that these halophytes could cover the essential nutrients for maintenance of small ruminants according to the recommended nutritional requirements of livestock in Egypt as indicated by Kearl (1982**).** Halophyte plants spreading in Egyptian desert and coastal areas are considered as a source of forage and fodder because of their fair content of protein (El Shaer *et al*. 2005).

Table 5: Nutritional values of the tested halophytic plants species

Plant species	CP	CF	Ash	ADF	NDF	EE	NFE
Leptochloa fusca	10.02	29.36	29.35	22.63	13.69	2.56	28.71
Kochia indica	10.11	25.64	34.26	24.36	13.23	2.31	27.68
Sporobolus virginicus	10.2	29.56	29.42	23.69	13.36	2.44	28.38
Salicornia europeae	8.32	34.86	26.35	22.65	13.36	2.22	28.25
Spartina patens	9.99	31.02	31.26	24.41	13.23	2.42	25.31
LSD 5%	0.63	3.25	3.35	3.02	0.75	0.12	3.66

Lignocellulosic biomass in different plant species grown under 50% lake water irrigation

The tested halophytes have desirable cellulose/hemi-cellulose and low lignin contents (Table 6) which can lead to more sugar yield and subsequently more ethanol production through fermentation. The highest values for cellulose and hemi-cellulose were recorded in *S. virginicus*, while the highest value of lignin were in *K indica*. At present bioethanol is mostly produced from carbohydrate-rich plants. In this regard, Xianzhao *et al*.(2013) mentioned that in coastal zone , there are some halophytes such as *Helianthus tuberosus, Tamarix chinensis, Achnatherum splendens, Phragmites australis* etc., which can be irrigated directly with seawater and have great potential to produce fuel alcohol. They added that wide coastal tidal flat can offer excellent environmental conditions for fully utilizing and cultivating halophytic energy plants at a large spatial scale, which will have a great potential of supplying bio-energy. The feasibility of converting ligno-cellulosic vegetative biomass of halophytic plants into sugar, which is subsequently fermented to ethanol, opens new venues to tackle the problem of "food or fuel". Halophytes grow under conditions where both available water and soil are saline. Therefore use of halophytes as biofuel crop is advantageous because they do not compete with conventional crops for high quality soil and water and hence do not encroach on the resources needed for food crops (Rozema and Flowers 2008).

Halophytes may have several unique features ranging from distribution and growth habitat to aspects of composition that make them a potentially interesting bio-resource for biofuels. The conversion of ligno-cellulosic material into ethanol involves hydrolysis of cellulose through cellulase enzyme and fermentation of the sugar formed by yeast or bacteria. This research suggests that halophytes can compete favorably with other conventional sources for biofuel production. These plants are abundant in nature, are outside the human food chain and require low maintenance which makes them relatively inexpensive to grow. Abideen *et al*. (2011) stated that bio-ethanol from ligno-cellulosic biomass is widely recognized as an environmental friendly and acceptable substitute for gasoline or as an additive to gasoline because it releases only that much CO_2 which it absorbed during photosynthesis. Ling (2010) added that most of energy halophytic species with the properties of drought tolerance, salinity-resistant and high net productivity are found to be suitable for growing in salt affected soil.

Table 6: Linocellulosic biomass of some halophytic plants (under 50% saline water irrigation treatment)

Plant species	Cellulose %	Hemi-cellulose %	Lignin %
Leptochloa fusca	28.36	26.35	10.11
Kochia indica	29.54	25.14	12.25
Sporobolus virginicus	31.23	27.45	9.68
Salicornia europeae	28.65	26.02	11.23
Spartina patens	25.37	26.36	9.54
LSD 5%	2.15	1.83	0.75

Conclusions

The study indicates that halophytic plant species are suitable for planting in saline environments and can facilitate the adaptation of agriculture to the increasing salinization and decreasing availability of fresh water. Thus many salt affected soils unsuitable for agriculture can be turned into productive agricultural areas. The halophytes do not compete for good quality water and productive farmlands. They can be potentially used to produce huge amounts of biomass while grown with brackish water on saline land, without competing with conventional agriculture. Growing salt-tolerant plants in saline soil can also improve the ecological environment and enhance land productivity of these marginal lands by producing forage, fodder, and biofuel feedstock.

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Drought assessment in a typical rainfed agricultural region of Inner-Mongolia, China

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Abstract

Agricultural drought is a type of natural disaster that has a serious impact on food security. Because the relationships among short-term rainfall, soil moisture, and crop growth are complex, the accurate identification of a drought situation is difficult. In this study, using a conceptual model based on the relationship between water deficit and yield reduction, we evaluated the drought process in a typical rainfed agricultural region, Hailar County in Inner Mongolia, China. To quantify drought, we used the three precipitation indices (Precipitation Anomaly (PA), Standardized Precipitation Index (SPI), Effective Drought Index (EDI), and the soil moisture–based Crop Moisture Index (CMI) as well as the Normalized Difference Vegetation Index (NDVI). Correlation analysis was conducted to examine the relationships between dekad-scale drought indices during the growing season (May–September) and final yield, using data collected from 2000 to 2010. The results showed that the yield has positive relationships with both EDI and CMI from mid-June to mid-July and with the NDVI anomaly throughout July. Further analysis of the relationship between the drought indices showed that the NDVI anomaly responds to both EDI and CMI with a lag of 1 dekad, particularly in July. To examine the feasibility of employing these indices for monitoring the drought process at a dekad time scale, a detailed drought assessment was carried out for selected drought years. It confirmed that the drought indices in the late vegetative to early reproductive growth stages can be used to detect agricultural drought in the study area. Therefore, the framework of the conceptual model developed for drought monitoring can be employed to support drought mitigation in the rainfed agricultural region of northern China.

Introduction

Agricultural drought is the most frequent natural disaster and causes the heaviest crop damage in Inner Mongolia (Shen 2008). Accurate quantification of drought is difficult because its definition varies among climatic zones and it is context-dependent (Quiring, 2009). Following the definition of drought by the UNCCD (1994), in this study we consider agricultural drought to be a "naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems." To manage drought conditions, it is necessary to evaluate the status of the entire water cycle by looking at all available indicators to identify multiple aspects of the drought situation. Some assessment studies have focused on the essential characteristics of drought (Donald 1994): intensity, duration, and spatial coverage. Other assessments have evaluated the impact of drought based on these basic characteristics, such as Vegetation Drought Response Index (Brown et al. 2008) and studies based on multiple-year drought conditions (e.g., drought vulnerability assessment by Zarafshani *et al.* 2012; drought risk assessment by Zhang *et al.* 2004). With regard to drought occurrence, the onset of an agricultural drought may lag that of a meteorological drought, depending on the prior moisture status of the surface soil layers (Heim 2002). There appears to be an inherent temporal relationship between shortage of rainfall and yield damage. In addition, according to the UNCCD (1994) definition, it considers temporal relationship: firstly, there is shortage of precipitation, and then agricultural drought occurs when vegetation suffers from a water deficit. Therefore, to accurately identify the features of agricultural drought in a specific region, it is necessary to examine the underlying drought process.

Numerous drought indices have been developed to simplify the identification of agricultural drought, and these indices can be divided into three groups. The first group is precipitation indices, such as Precipitation Anomaly (PA), Standardized Precipitation Index (SPI) (McKee *et al.* 1993, 1995), and Effective Drought Index (EDI) (Byun and Wilhite 1999). The second group is soil moisture–based indices, such as the Palmer Drought Severity Index (PDSI) (Palmer 1965) and Crop Moisture Index (CMI) (Palmer 1968). CMI responds rapidly to changing conditions, it has therefore advantages over PDSI in agricultural drought studies. The third group is vegetation-based indices, including the Ratio Vegetation Index (Jordan 1969), Normalized Difference Vegetation Index (NDVI) (Rouse *et al.* 1974), and Enhanced Vegetation Index (Huete *et al.* 2002). Among the vegetation indices, NDVI is the one most often used and it is an operational, global-based vegetation index (Huete and Justice 1999). NDVI was widely used in research on vegetation dynamics (Zhou *et al.* 2009; Duan *et al.* 2011) and drought spatial monitoring (Kogan and Sullivan 1993; Kogan 1994, 1997). Therefore, we selected five short-time indices (PA, SPI, EDI, CMI and NDVIA) for drought process assessment.

The relationship between moisture shortage and crop growth is the key link in the agricultural drought process. Previous drought studies showed great variation in the relationship between moisture shortage and satellite-derived drought indices. For example, Bayarjargal *et al.* (2006) found no agreement between the spatial extent of satellite-derived drought indices and monthly PDSI. Quiring and Ganesh (2010) reported that monthly relative NDVI change index (vegetation condition index) is most strongly correlated with prolonged moisture stress, including 6-month SPI, 9-month SPI, and PDSI, and less sensitive to short-term precipitation deficiencies than to long-term ones (Quiring and Ganesh 2010). The temporal scale of a dekad is often used in agricultural studies. In this study, we used short-term (dekad) vegetation variation to assess the ability of several indices to describe the agricultural drought process.

The overall objective of this study was to construct a framework to assess the agricultural drought process based on a conceptual model. We then examined the relationships among indices and the temporal interaction of factors on a short time scale during the drought process. The specific objectives were to: (1) clarify trends of dekad-scale PA, SPI, EDI, CMI, and NDVI during the growing period, (2) examine the relationships between drought indices and crop yield, (3) evaluate the temporal relationships among the drought indices, mainly focusing on water shortage accumulation and time lag, and (4) assess agricultural drought over a long-term period.

Conceptual model of the agricultural drought process

The agricultural drought process refers to the water balance within the weather–soil–crop agricultural production system. The key link during the drought process can be simplified as a temporal sequence of precipitation, soil moisture, vegetative growth, and yield. In rainfed agricultural regions, precipitation is the main water source, and yield is the final outcome of the drought process. During the generation of water stress, there is a time lag in the effect of soil moisture on vegetation vigor. Figure 1 illustrates the drought process over the growing period of crops in rainfed agricultural regions. Following this framework, we use dekad–scale PA, SPI, EDI, CMI, NDVI, and yield as input for an assessment of the agricultural drought process.

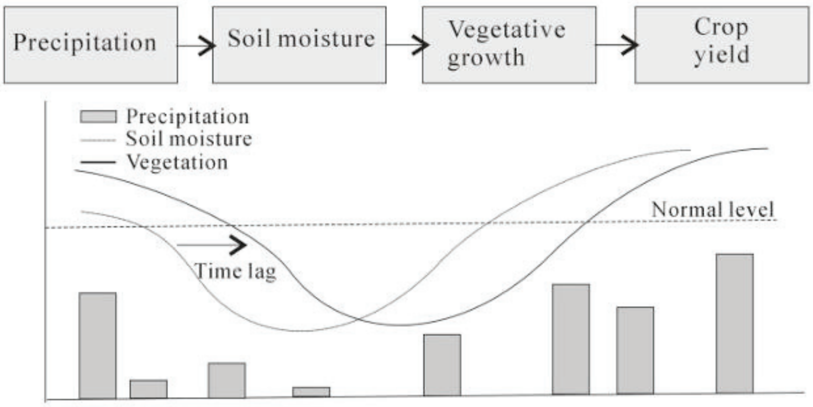


Figure 1: Schematic diagram of the drought process during the crop growing period in a rainfed agricultural region.

Materials and methods

Study area

The study area is Hailar County (total area 1440 km^2; Fig. 2), which is located in the northeastern part of the farming-pastoral ecotone of northern China. Chestnut soil is the main soil type, and the soil texture is loamy sand and loam (USDA classification, FAO soil map). Hailar County is in the semi-arid region (aridity index = 0.46) of China. Average annual precipitation (1971–2010) is 348.33 mm. About two-thirds of the annual precipitation occurs from June to August. In cold winters, the monthly temperature in January falls to minus 25.8°C. There is 4–5 months of continuous snow cover each year (Jin *et al.* 2000; Li and Mi 1983), and a short growing period (May to September). In 2009, 97% of the farmland was un-irrigated. Large areas of homogeneous

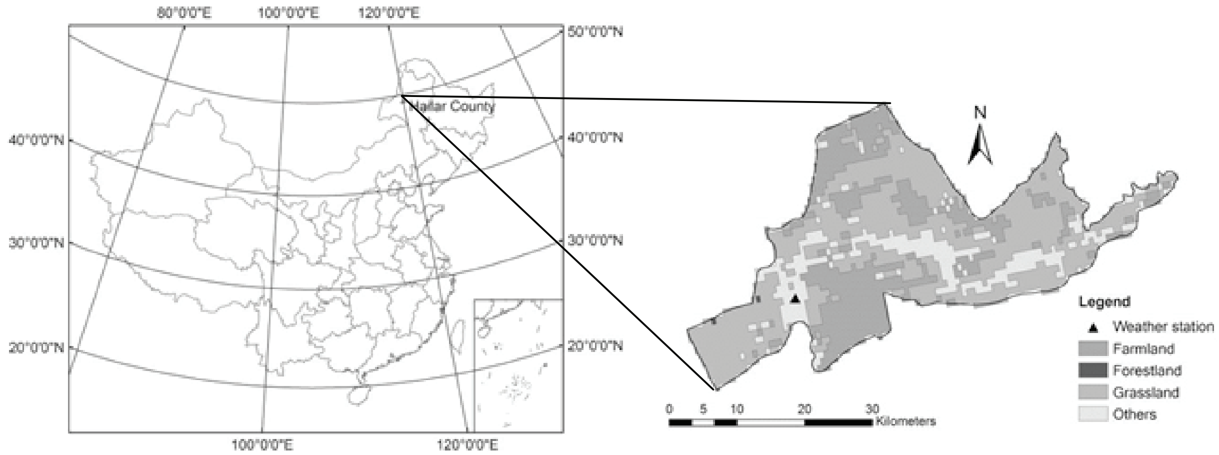


Figure 2: The location of Hailar County in China and distribution of land-use types (land-use information from 1-km grid land-use map of China in 2000).

cultivated plots exist in Hailar County, which is suitable for monitoring crop growth based on moderate-resolution remote-sensing technology. Spring wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) play an important role in the agricultural production of Hailar County.

Data collection

Daily meteorological data, including precipitation, temperature, relative humidity, wind speed, and hours of sunshine, from the Hailar weather station (1951–2010) were downloaded from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). MODIS daily 500-m products (MOD09GA h25v4) from May to September for the years 2000 to 2010 (for a total of 1641 products) were downloaded from the U.S. Geological Survey's website (https://lpdaac.usgs.gov/). A land-use map of China in 2000 (1:1,000,000, 1-km grid, WESTDC) was downloaded from the Environmental and Ecological Science Data Center for West China, National Natural Science Foundation of China and Data-sharing Network of Earth System Science (http://westdc.westgis.ac.cn). The water content in Hailar County available for farmland was calculated by area-weighted method using the available water content records noted on a 1:1,000,000 scale soil map of China provided by the Chinese Academy of Sciences (downloaded from FAO Harmonized World Soil Database v 1.2, http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/).

Crop planting area and yield data from 1993 to 2010 were collected from the Hailar Statistics Bureau. Yield energy analysis can measure total agricultural output of the farmland as well as the environmental contribution to crop production. The coefficients of the food energy obtained from the main crops in Hailar were taken from Shu *et al.* (2008). The values are 16.3×10^6 J/kg for wheat and barley grain, 20.9×10^6 J/kg for soybeans, 16.3×10^6 J/kg for maize, 4×10^6 J/kg for fresh potato, 26.3×10^6 J/kg for oil rape, 2.5×10^6 J/kg for vegetables, and 1.1×10^6 J/kg for melon. Then, using the sowing area and production data for these eight types of crops during 2000–2010, the yield energy per unit area was estimated for Hailar County.

Calculations of drought indices

PA and SPI: PA is the one of the most popular simple drought indices. The equation is following

$$PA_{i,j} = \frac{P_{i,j} - P_{\mathrm{ave},j}}{P_{\mathrm{ave},j}} \times 100 \qquad (1)$$

where i is year, j is dekad, and $P_{\mathrm{ave},j}$ is the average value for the same dekad j during 1951–2010. The SPI requires a long-term precipitation record to fit the gamma probability density function to the observed data (Zhou *et al.* 2001). Using the dekad data from 1951 to 2010, we calculated the dekad SPI by using the method of McKee *et al.* (1993, 1995) for monthly data.

To account for the antecedent rainfall of SPI in the effect on other factors, PA and SPI was calculated with the simple averaging method using the following equation $PA = \frac{\sum_{k=s-n+1}^{s} \mathrm{PA_k}}{n}$ and

$PA_n = \frac{\sum_{k=s-n+1}^{s} PA_k}{n}$ respectively, where n is the total number of the dekads considered, and s is ascending time serial number of dekad.

EDI: Byun and Wilhite (1999) developed the EDI to detect a drought and its beginning, end, and accumulation stress. The following equations were used for daily EDI calculations:

$$\mathrm{EP_D} = \sum_{n=1}^{\mathrm{D}} \left[\left(\sum_{m=1}^{n} P_m \right) / n \right] \quad (2)$$

$$\mathrm{DEP=EP\text{-}MEP} \quad (3)$$

$$\mathrm{PRN=DEP} / \sum_{\mathrm{k}=1}^{\mathrm{D}} \frac{1}{\mathrm{k}} \quad (4)$$

$$\mathrm{EDI=PRN}/\sigma_{\mathrm{PRN}} \quad (5)$$

where $\mathrm{EP_D}$ represent the valid accumulations of precipitation from a particular date; D is duration of summation begins from 365; $\mathrm{P_m}$ is precipitation of m days before. DEP shows the deficiency or surplus of water resources for a particular date and place; MEP is 30-yr mean of EP for each calendar day. In order to reflect the drying effect on the soil from a drought that occurred several years ago, when DEP is negative for two consecutive days, "D" becomes 366(=365+2-1) and the calculation begins once again; PRN is one day's precipitation needed for a return to normal condition; σ_{PRN} is the standard deviation of the relevant PRN.

The EDI program (FORTRAN (90)) was downloaded from http://atmos.pknu.ac.kr/~intra2/. The daily EDI for Hailar County were calculated using program. Finally, in this paper, dekad EDI were processed by using the simple average method based on daily EDI.

CMI: The CMI (Palmer 1968) is based on a subset of the calculations required for the PDSI (Palmer 1965). The origin CMI begins with a water balance using historic records of precipitation and temperature. Considering the short-term moisture supply and the moisture demand of the crop, CMI is the sum of evapotranspiration deficit and excessive moisture. The equations for these two aspects and CMI are as follows:

$$Y_i = 0.67Y_{i\text{-}1} + 1.8\frac{ET_i\text{-}(\alpha \times ET_{oi})}{\sqrt{\alpha}} \quad (8)$$

$$G_i = G_{i\text{-}1}\text{-}H_i + (M_i \times R_i) + RO_i \quad (9)$$

$$\mathrm{CMI_i} = Y_\mathrm{i} + G_\mathrm{i} \quad (10)$$

where Y_i is an index of evapotranspiration deficit for dekad i; ET is actual evapotranspiration; ET_o is potential evapotranspiration; α is a water balance coefficient; G_i is an index of excessive moisture for dekad i; H is a "return-to-normal" factor; M_i is the average percent of field capacity; R_i is recharge; and RO_i is runoff.

The C++ package for computing CMI (scPDSI, version 2.0) was downloaded from http://greenleaf.unl.edu/downloads/scPDSI.zip. The original method for computing potential evapotranspiration (ET_o) is based on the weekly Thornthwaite method (Thornthwaite 1948). To obtain the 10-day estimation of ET_o, the Penman–Monteith FAO 56 (PMF-56) model was introduced to modify the program (Allen *et al.* 1998). The PMF-56 model is recommended as the sole method for determining ET_o, and it has been widely accepted as superior to other methods in China (Cai *et al.,* 2007). To estimate dekad ET_o, the daily temperature, humidity, wind speed, and hours of sunshine data were used to calculate daily ET_o. Then, dekad CMI values were obtained based on dekad-scale data from 1951 to 2010.

NDVI anomaly: In this study, we used MOD09GA bands 1 and 2, a band quality map, and a 1-km reflectance state map from each daily MODIS product (h25v4). Bands 1–2 were first used for computing daily NDVI images according to Rouse *et al.* (1974). The 10-day synthesized NDVI as well as corresponding synthesis quality maps were produced based on daily images following the maximum-value composite procedure (Holben 1986). Finally, with the help of the quality map, the noise was removed from the images. Due to a lack of images for vegetation indices from 15 June to 1 July 2001, there is no value for the third dekad of June 2001. The farmland NDVI series was built using the MODIS dataset and a farmland mask that is extracted from the land-use map of China. Considering the farmland of the county as a whole, the NDVIA was calculated with the following equation:

$$\mathrm{NDVIA}_{i,j} = \frac{\mathrm{NDVI}_{i,j} - \mathrm{NDVI}_{\mathrm{ave},j}}{\mathrm{NDVI}_{\mathrm{ave},j}} \times 100 \qquad (11)$$

where i is year, j is dekad, and $\mathrm{NDVI}_{\mathrm{ave},j}$ is the average value for the same dekad j during 2000–2010. The average value was computed using all the records in the same dekad.

Statistical analysis

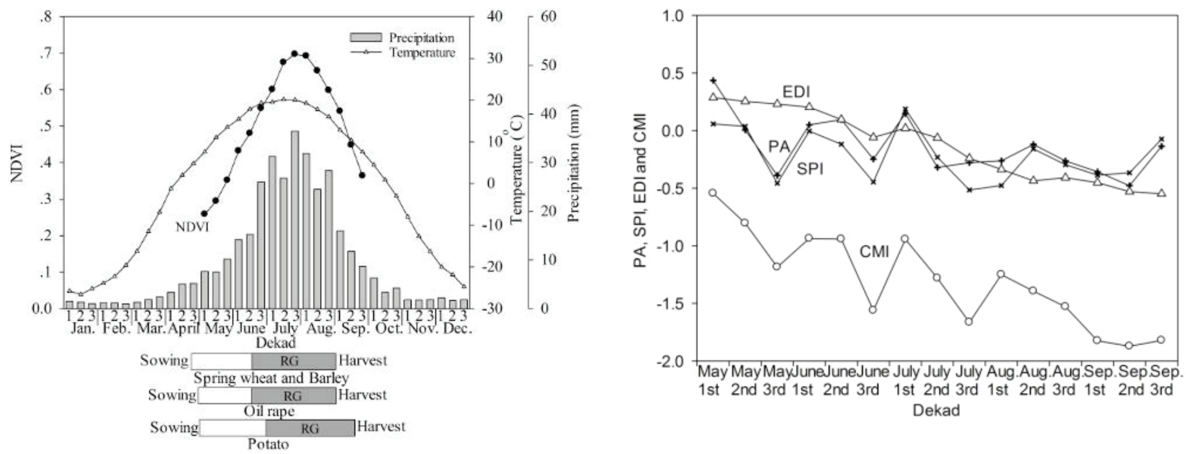
The correlation of determination (R^2) measures the strength of a linear relationship between two variables. The statistical significance enhances its confidence by judging probability of occurrence due to chance (p-value). Using SPSS ver. 13.0 software (SPSS, Inc., Chicago, IL, USA), we calculated R^2 and its significance level to identify the main period during which yield is sensitive to drought indices and the temporal relationships among the various indices during the drought process.

Results

Seasonal trends of drought indices

The average NDVI began to increase in early May and exceeded 0.3 in late May, when the average dekad temperature was higher than 0°C; at this point, crop growth accelerated until the curve reached a peak in mid-July (Fig. 3a). After that, the NDVI decreased sharply until late

September, when the average dekad temperature again decreased to 0°C. With regard to local crop phenology, due to the short growing period in Hailar County, when the temperature reaches its peak in July, most of the crops are just reaching the flowering stage. From 2000 to 2010, PA and SPI indicate that precipitation during late May, late June, and from late July to early August were lower than average level. Both of EDI and CMI show a tendency for decrease across growth period (Fig. 3b). Reproductive growth (RG) periods of main crop in Hailar county are after late June. There was higher drought risk on agricultural production in Hailar County.



(a) (b)

Figure 3: The average dekad NDVI (a) and PA, SPI, EDI and CMI (b) from 2000 to 2010 during the growing period. Panel (a) also shows the median temperature and average precipitation during 1951–2010 and crop phenology. Phenology information (Sowing, harvest and reproductive growth (RG) period) was obtained from Zhang et al. (1987) and local monograph by Wang and Zhao (2006) and interviews with staff of the Hailar Agricultural and Animal Husbandry Bureau.

Relationships of drought indices with crop yield

The key period for dekad-scale CMI was from the second dekad in June to the second dekad in July, similarly, EDI was from third dekad in June to the second dekad in July (Table 1). The key period for NDVIA is from the first to the third dekad in July. There was clear seasonality in the relationship between yield and these indices. Our analyses revealed no clear sensitive dekad for PA, SPI. However, with regard to average PA and SPI values, there was a significant correlation with yield energy in May–June, May–July and May-August (Table 2).

Temporal relationships between drought indices

The correlation of multi-dekad average PA, SPI with CMI and NDVIA, PA and SPI show a similar tendency of increase. The R^2 between CMI and multi-dekad average PA, SPI was higher than that between multi-dekad average PA, SPI and NDVIA. The strongest correlation for CMI was with the average multi-dekad average PA, SPI of four dekads (Fig. 4a). The strongest correlation for the NDVIA was with multi-dekad average indices of six dekads (Fig. 4b). Thus, a precipitation

Table 1: The coefficient of determination (R^2) between dekad-scale indices and crop energy yield anomaly in Hailar County during 2000–2010 (n = 11)

Index	May			June			July			August			September		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
PA	0.017	0.007	0.201	0.060	0.223	0.310	0.178	0.015	0.052	0.337	0.076	0.071	0.019	0.084	0.022
SPI	0.006	0.039	0.069	0.028	0.217	0.327	0.136	0.019	0.014	0.455*	0.051	0.023	0.008	0.022	0.007
CMI	0.002	0.003	0.035	0.139	0.814**	0.630**	0.526*	0.638**	0.160	0.012	0.027	0.081	0.602**	0.002	0.003
EDI	0.000	0.013	0.007	0.188	0.331	0.497*	0.590**	0.580**	0.299	0.045	0.004	0.166	0.209	0.096	0.077
NDVIA	0.204	0.24	0.000	0.097	0.087	0.249	0.723**	0.665**	0.647**	0.176	0.042	0.157	0.244	0.072	0.029

Note: 1st, 2nd, and 3rd refer to the three dekads within each month. For NDVIA, n=10 in the 3rd dekad of June.

* Statistically significant at the 0.05 level.
** Statistically significant at the 0.01 level.

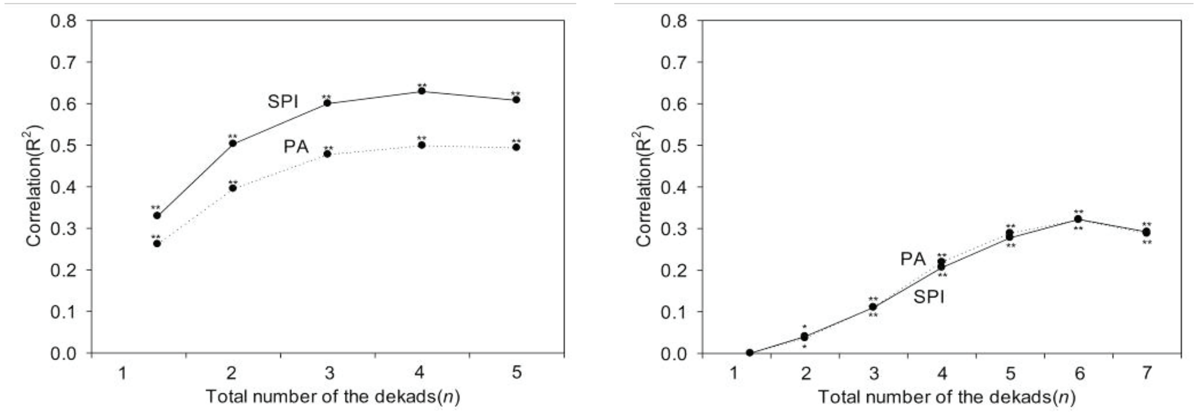
Table 2: The coefficient of determination (R2) between multi-dekad average values of indices and crop energy yield anomaly in Hailar County during 2000–2010 (n = 11)

Index	May	May–June	May–July	May–August	May–September
PA	0.015	0.598**	0.544**	0.484**	0.292
SPI	0.023	0.587**	0.388*	0.588**	0.538*
CMI	0.006	0.523*	0.638*	0.623*	0.602**
EDI	0.000	0.116	0.314	0.287	0.296
NDVIA	0.073	0.136	0.403*	0.356	0.205

*Statistically significant at the 0.05 level. ** Statistically significant at the 0.01 level.

shortage within a particular dekad does not directly influence the CMI and vegetation; rather, this occurs through a cumulative process.

When considering the correlation between CMI and the performance of the NDVIA from May to September over the 2000–2010 study periods, the strongest correlation existed with a 1-dekad time lag, the similar correlation also exists for EDI (Fig. 5a). By considering the relationship between CMI and NDVIA for each month separately, the maximum R^2 ranged from 0.319 (September) to 0.619 (July). The highest correlations between these indices occurred in July and showed a 1-dekad time lag (Fig. 5b). Similar to CMI, between EDI and NDVIA for each month, the maximum R^2 ranged from 0.193(September)-0.651(July) and also showed a 1-dekad time lag in July (Fig. 5c). There is high correlation between CMI and EDI (Fig. 5d).

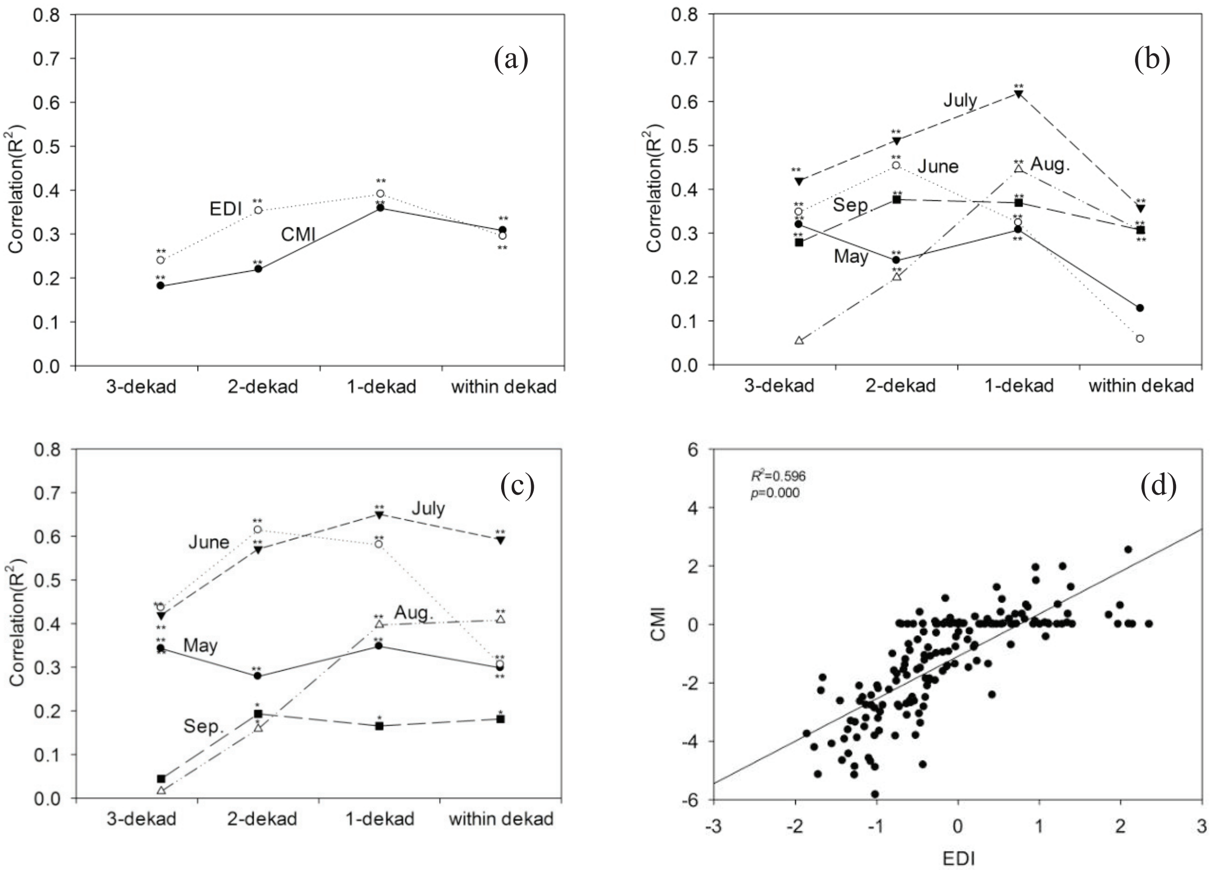


(a) Average PA, SPI and CMI (n=165) (b) Average PA, SPI and NDVIA (n=164)

Figure 4: The coefficient of determination (R^2) between multi-dekad average PA, SPI and CMI (a) and PA, SPI and NDVIA (b) during May to September from 2000 to 2010 in Hailar County. The x-axes denote the total number of dekads considered, with, for example, 6 indicating 6 dekads average. * Statistically significant at the 0.05 level; ** statistically significant at the 0.01 level.

Drought assessment

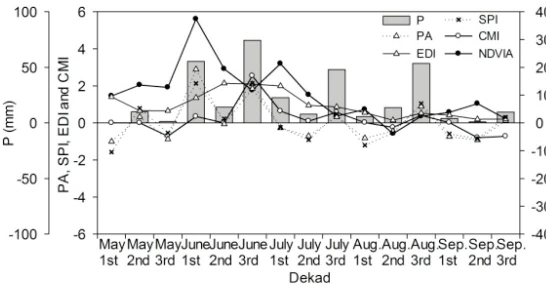
During 2000–2010, yield was heavily reduced in 2001, 2003, 2004 and 2007. For each of these years, as assessed by PA, SPI, EDI, CMI and NDVIA, there was a time lag between CMI and NDVIA (Fig. 6). The year 2003 had the most serious yield reduction. The CMI value in the first dekad of May was less than –2, indicating that there was a lack of soil moisture before the growing season. After sowing, from early May to early July, the precipitation values were continuously low. This long-term precipitation shortage caused a gradual decrease in CMI until mid-July. The shortage of water ultimately caused a continuous decrease in the NDVIA. Precipitation recovers to normal from mid-July to early August, so the CMI value increased and returned to normal. The recovery of soil moisture also prompted the recovery of NDVI. The vegetation condition returned to normal in mid-August. However, this recovery period occurred too late in the growing season. Therefore, the yield was heavily reduced due to this spring and summer drought.



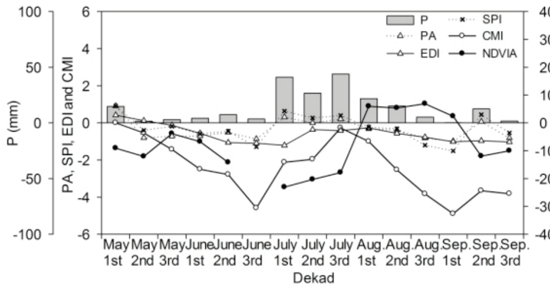
(a) Growing period for CMI–NDVIA and EDI–NDVIA (n=164); (b) Individual months for CMI–NDVIA (n = 33); (c) Individual months for EDI–NDVIA (n = 33); (d) Growing period for CMI–EDI (n=165)

Figure 5: The coefficient of determination (R^2) between CMI and EDI (a), CMI and NDVIA, EDI and NDVIA over the entire growing period(a) ,between CMI and NDVIA, EDI and NDVIA in individual months (May to September) (b–c) and between CMI and EDI(d) from 2000 to 2010 in Hailar County. The x-axes denote the time lag between the dekad-scale indices. In panel (b), n = 32 for June. *Statistically significant at the 0.05 level; **statistically significant at the 0.01 level.

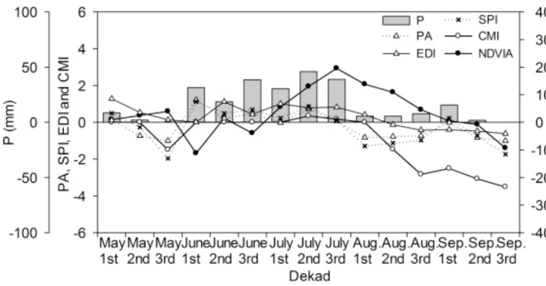
In contrast, the serious period of drought in 2007 was in summer and autumn. The precipitation in mid and late May provided good moisture conditions during the crop seeding period. The NDVIA showed that the growth condition was even better than normal. However, there was a series of dekads after mid-June when precipitation was lower than normal, particularly the dekad in late July, with only 0.4 mm precipitation. CMI showed that water stress rose to the most serious point in late July. Due to this water stress, NDVIA decreased sharply and fell to the lowest point in mid-August. Although the precipitation in August returned to normal, the NDVIA recovered to normal levels in mid-September. By that point the crops had already passed through the flowering stage, and the yield suffered great damage.



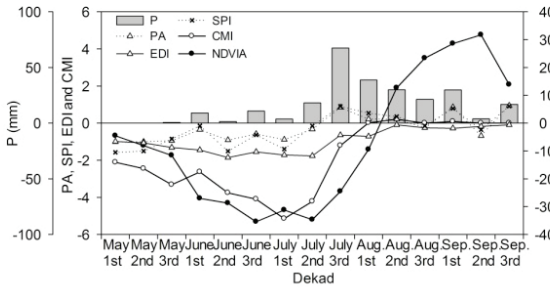
2000 (5.64)



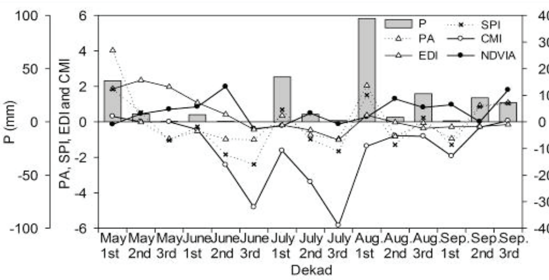
2001 (2.07)



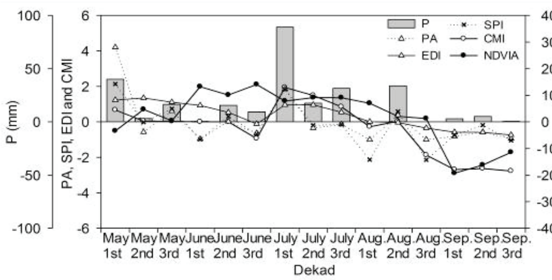
2002 (4.15)



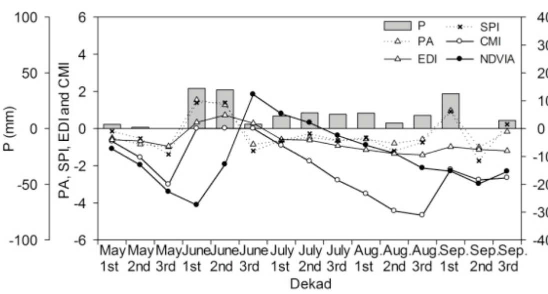
2003 (1.28)



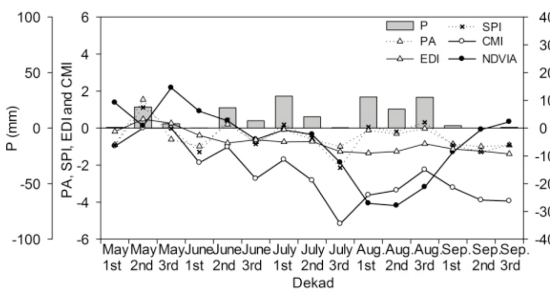
2004 (2.56)



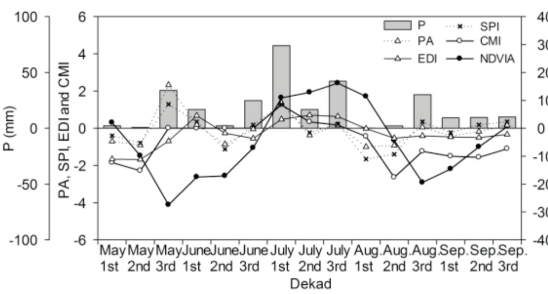
2005 (5.25)



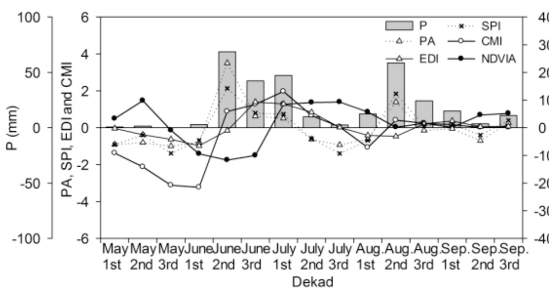
2006 (4.12)



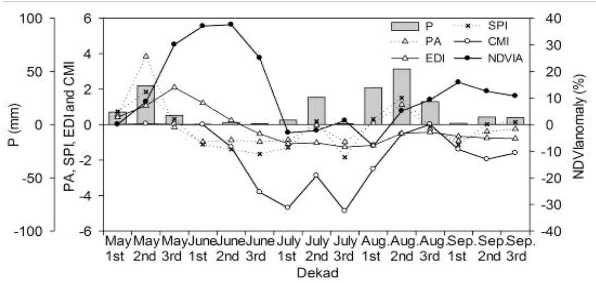
2007 (3.12)



2008 (6.08



2009 (6.43)



2010 (4.15)

Figure 6: Drought process as depicted by PA, SPI, EDI, CMI, and NDVIA from 2000 to 2010 in Hailar County. On the *x*-axes, values in parentheses represent the total crop yield energy ($\times 10^7$ kJ/ha).

Discussion

Recent trends of climate and agricultural drought in Hailar County

The frequency of extreme drought in northeastern China has obviously been increasing since the 1980s, which is closely related to decreased precipitation and increased temperature (Ma and Fu 2006). Since 2000, this dry and warm trend has been significant in Hailar County (Fig. 3b). In addition, the decrease in precipitation influenced the moisture balance and increased water stress on crops. Because the water deficit occurs during the key reproductive growth period (flowering time) of crops, the energy yield has suffered greatly from the water deficit. These findings suggest that in semi-arid regions such as Hailar County, the drying and warming climate trends that have occurred during the growing season over the past decade mean that meteorological drought has easily transformed into agricultural drought.

Critical growth stages related to yield reduction

Our results showed that vegetation vigor as measured by NDVI best reflects yield energy in July (Table 1). It is similar to the research by Deng *et al.* (2011) in northern Hailar County and Chen Barag Banner (adjacent to Hailar County) and research conducted in the Canadian prairies (Mkhabela *et al.* 2011). In Hailar County, the grain-filling stage for spring wheat is in mid-July. The research by Hirota *et al.* (1990) shows that the characteristics of flag leaves reflect photosynthetic activity and was considered to be one of the most important components in determining grain yield potential. It is possible that vegetation indices in July detect the growth condition of flag leaves and therefore perform well in monitoring yield damage. The key water stress period identified by dekad-scale CMI or EDI can be validated by research on crop water requirements. According to experiments on spring wheat in northern China, water consumption of spring wheat reached a peak during the jointing to milky period, which accounted for 47.5% of the total water consumption (Li et al. 2003). Perhaps the unbalanced state between the water supply and water consumption by spring wheat during this period is what allowed CMI or EDI in mid to late June to provide the best forecast of yield.

Time lags between water deficit and NDVI

Our findings show that both of the CMI and EDI at dekad scale bridge the gap between short-term vegetation change and water deficit as depicted by an *in situ* meteorological dataset. The equation (2) of EDI can be regarded as approximation of water balance from the aspect of usage of precipitation. In May, June, and September, the time lag between CMI (or EDI) and NDVI was longer than that in July and August, during the growing period (Fig. 5). The average time lag between CMI (or EDI) and NDVI was 1 dekad during the growing period. It is comparable to the previous study; the results by Zipporah (2011) showed that a 10-day lag between NDVI and soil moisture by microwave remote sensing was the dominant pattern in grassland, cropland, and shrubland. And, there was a 1- to 2-week time lag in the NDVI of grassland response to soil moisture variation in the 5- and 25-cm layers (Gu *et al.* 2008). The measurement of soil moisture at Ewenki, Ergun, and Zhalantun experiment stations (near Hailar County) showed that in spring, after snow melt, there is a period of significant soil moisture loss from early April to early June due to strong wind (Wang and Zhao 2006). CMI may perform poorly in depicting the soil moisture balance influenced by snow melt and strong wind in spring.

Feasibility of using multiple indices for monitoring agricultural drought

Our detailed assessment of the agricultural droughts in 2003 and 2007 shows that SPI, CMI, and NDVI can depict the processes underlying a serious drought at the dekad time scale during the growing season. PA and SPI can be used to estimate the accumulation of water stress. The relationship between CMI (or EDI) and NDVIA displays a significant time lag. In this study, although dekad-scale NDVI is based on maximum-value composite method, our results suggest that NDVI provides sufficient information to reflect the response of crops to drought at the dekad time scale.

Conclusion

Our findings indicate that the agricultural drought assessment model is suitable for regions where crop yield is closely related to the reproductive growth stage. In our assessment of four drought years based on the proposed model, we were able to track the drought process in Hailar County: we found that meteorological drought during 2000–2010 was easily transformed into agricultural drought. In this region where grain crops, including spring wheat and barley, are the main crop types, soil moisture–based and vegetation indices during the late vegetative to early reproductive growth stages (CMI in June and NDVIA in July, respectively) could be used to detect agricultural drought. The most frequent average time lag between CMI and NDVI was 1 dekad, especially in July. Such relationship can also be enhanced by time lag between EDI and NDVI. The results of this 11-year assessment at the dekad time scale in Hailar County fit the conceptual model of the agricultural drought process well. Our findings suggest that when synthesizing multiple indices to identify drought features at a short time scale, the underlying drought process needs to be considered. Future research of the drought process should consider the calibration of fixed parameters for CMI using cases of drought lasting for longer time periods, the effects of snow melt and strong wind on soil moisture in spring, the role of human activity, and the influence on yield of other disasters, such as insect attack. In regions with a dry and warm climate, such as that of Hailar County, longer term or more sustainable measures, such as adjusting the cultivation calendar or crop planting structure, may be necessary to prevent damage from agricultural drought in the future.

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Enhanced tropospheric ozone under global climate change situation and its effects on yield and some fatty acids in Thai soybean at Northern Thailand

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Abstract

The enhanced tropospheric ozone under global climate change situation has adverse effects on various crop species and leads to worldwide yield loss. Hence, an examination of aforementioned problem is warranted. In this research, the effects of ambient ozone and elevated ozone levels on Thai soybean (*Glycine max* (L.) Merrill) cultivar 'Chiang Mai 60' were investigated from December 2009 – March 2010 at the Naresuan University crop field, Phitsanulok, Thailand. Soybean was planted and covered with open top chamber (OTC) from seedling through maturity stage. OTC systems with charcoal filter and non - charcoal filter were set to control the O_3 at three different levels: ambient level (32 ppb), and lower (12 ppb) and higher (62 ppb) than ambient level. Results indicated that significant yield loss occurred. The number of pods per plant was reduced by 21.8 percent when plants were exposed to 62 ppb O_3 compared to the control (ambient level). In contrast, there was a positive effect in lipid content which was increased by 15.33%. The quantity of linoleic acid and linolenic acid increased by 13.6 % and 10.74%, respectively. This study clearly indicated that the elevated ozone concentration could suppress yield in soybean but induced an increase in the quantity of some fatty acids.

Introduction

Anthropogenic emissions of chemical reactive trace gases have substantially altered the composition of the troposphere. Among pollutants, ozone (O_3) is one of the important species that have received considerable attention (Ariyaphanphitak *et al.* 2005). It is one of the main pollutant gases affecting both human health and vegetation. O_3 plays an important role in controlling the chemistry and chemical composition of the troposphere. O_3 affects the energy budget of the atmosphere by absorbing and emitting infrared radiation in the 9.6 µm band and by strongly attenuating solar radiation in the visible and ultraviolet regions. Several modeling studies have indicated that such a perturbation may strongly influence global climate; for example, a 15-50% increase in the tropospheric O_3 amount may result in a temperature increase of 0.1-0.4°C (Fishman 1991; Wang *et al.* 1993; Puckrin 1996). Photo-dissociation of ozone by solar UV radiation will produce electronically excited $O(^1D)$ atoms by way of R1 : $O_3 + h\lambda \rightarrow O(^1D) + O_2 \lambda 6325$ nm followed by reaction of the metastable $O(^1D)$ with water by way of R2 : $O(^1D) + H_2O \rightarrow 2OH$.

Laboratory investigations have shown that reaction R1 can occur in a spin-forbidden mode at wavelengths between 310 and 325 nm (Michelsen *et al.* 1994; Guicherit and Roemer 2000). The oxidation efficiency of the atmosphere is primarily determined by OH radicals, because a variety of atmospheric species, including the precursors of ozone namely CO, NO_2 and volatile organic compounds (VOC) are removed from the atmosphere by reaction with OH (Guicherit and Roemer 2000). The main drivers for increasing O_3 in the troposphere are higher concentrations of volatile organic compounds (VOCs) and of nitrogen oxides (NO_x) which react in the presence of sunlight to form O_3(Fowler *et al.*1999). The trend for O_3 concentration increase is 5-20 % per decade in Europe. The increase occurred primarily before 1985 (Zouzoulas *et al.* 2009). The average tropospheric concentration of O_3 in the Northern Hemisphere has more than doubled in the past 100 years (Hough and Derwent 1990). In many industrialized regions, the increase in tropospheric ozone is a key factor of atmospheric change (Fuhrer 2003).

Tropospheric O_3 is presently the third most important indirect greenhouse gas. Because of its impact on human health and wide spread occurrence of plant damage (Heagle 1989; Guicherit and Roemer 2000; Fuhrer 2003;IPCC 2007) effects of O_3 pollution on crops have received considerable research attention. Tropospheric O_3 is increasing in many agricultural regions, resulting in direct negative effects on stomatal conductance, photosynthetic C fixation, leading to productivity losses of sensitive crop species (Guicherit and Roemer 2000; Fuhrer 2003). Avnery *et al.* (2011) examined the potential global risk of increasing surface ozone (O_3) exposure to soybean (and maize, and wheat) in the near future (year 2030) according to two trajectories of O_3 pollution: the IPCC Special Report on Emissions Scenarios (SRES) A2 and B1 storylines was applied with Model MOZART-2, to calculate crop yield reductions resulting from O_3 exposure projected in 2030. The results showed that in the A2 scenario, global year 2030 yield loss of wheat due to O_3 exposure would range from 5.4 to 26% (a further reduction in yield of +1.5-10% from year 2000 values), and for soybean 15-19% (a reduction of +0.9-11%).

Understanding the responses of vegetation to increasing O_3 has important implications for assessing future productivity, ecosystem functioning and climate feedbacks (Mauzerall and Wang 2001; Fiscus *et al.* 2005; IPCC 2007). Soybean is one of the four most important agricultural species worldwide, and it is one of the crops known for their sensitivity to O_3 (Thanacharoenchanaphas and Rugchati 2010; Bernacchi *et al.* 2011). It has been estimated that soybean seed yields are suppressed by about 10% and 40% by O_3 concentration of 50 ppb and 70 ppb, respectively (Heagle 1989; Thanacharoenchanaphas and Rugchati 2010). In future, the higher air temperatures because of elevated O_3 could lead to more changes in the productivity of soybean cultivars (Bernacchi et al. 2011).

In Thailand, soybean is grown in a variety of locations. The soybean area in Thailand has increased from 0.36 million rais (1 rai =0.16 ha) in 1972 to approximately 2.67 million rais in 1990 .The dominant production area is in the northern region which gives 74 percent of total production (Jierwiriyapant *et al.* 1992). However, this area has been covered by industrial and urban activities. One consequence of the industrialization and urbanization is the increase in O_3 precursors such as NO_2 and VOC, thus leading to a negative impact on soybean. We therefore carried out the research to assess the effects of elevated O_3 on yield and the concentration of some important fatty acids in soybean in northern Thailand. We hypothesize that raised O_3 concentrations will alter yield production and some nutrients of Thai soybean Chiang Mai 60.

Materials and methods

Research site: The study area was a suburban area in the Phitsanulok province, northern Thailand. It is located at coordinates 16 degrees and 44.003 minutes north of the equator, and 100 degrees and 11.810 minutes east of Prime Meridian. The site was in the agricultural farm of Naresuan University, Phitsanulok. The total study area covered about 200 m^2.

Experimental design and Ozone exposure: Exposure of soybean cultivar ‘Chiang Mai 60’ to three different O_3 level treatments was carried out in a open top chamber (OTP). The OTP (3 m long, 3 m wide and 2 m high) was constructed from a transparent plastic (Fig.1.). Ventilation fans were equipped in the front of the chamber to facilitate air circulation and to equilibrate the temperature difference between inside and outside of the chamber. Three levels of O_3 concentrations - ambient level (32 ppb), and lower (12 ppb) and higher (62 ppb) than ambient level - were set up. Randomized Complete Block Design (RCBD) with three replications was used. In the first treatment , the ambient air flown into the growth chamber was passed through activated carbon to eliminate O_3 (designated as CF). The second treatment used only ambient air (without activated carbon; designated as NCF). This treatment was used as control. In the last treatment (designated as CF-Ozone), the O_3 level was elevated by ozone generator (Belle Marketing Co.LTD, Thailand Model OZ-3020) and detected by photometric O_3 analyzer (model 400 E).

Figure 1: Open Top Chamber (OTC) and its system for ozone concentration control

Soybean management: Thai soybean ‘Chiang Mai 60’ was grown in the OTC from the end of December 2009 to March 2010. Soybean seeds were geminated and then hill sown, with 3 seeds per hill, in three rows using a spacing of 50 x 20 cm spacing. At vegetative growth stage – third node (V3) - all the plants were exposed to three different O_3 concentration levels for 7 hr (9.00 am – 4 pm) each day and this was continued until harvest.

Yield and nutrient content determination: Soybean plants were harvested at maturity (95 days after sowing). Samples were used to assess yield and nutritional value of seeds. Number of pod/ plant was used as the yield parameter. Fatty acid content of soybean seed was analyzed by AOAC (1995) method to estimate grain quality.

Statistical analysis: The grain yield and nutrition value data were analyzed statistically with analysis of variance (ANOVA). Significant difference of parameters were reported at $p<0.05$ by DMRT.

Results and discussion

Ozone concentration: The O_3 concentrations in 3 treatments (CF, NCF and CF-Ozone) were monitored for 3 months. From the O_3 generator in the chambers, the detected O_3 concentrations for 7 hr exposure for each treatment were 12 ± 10.1 ppb, 32 ± 11.1 ppb and 62 ±10.8 ppb for CF, NCF and CF-Ozone, respectively .

Yield: Seed production is the main parameter for estimating yield production. In this experiment, grain yield was examined by the number of seed-filled pod at maturity. The number of pods / plant were 25.76 ± 0.95, 21.10 ± 0.85 and 16.50 ± 0.46 for CF, NCF, and CF-Ozone treatments, respectively (Fig.2). It is clear that there was significant reduction ($p<0.05$, DMRT) in the number of pods/plant in CF-Ozone treatment. The percentage reduction under CF-Ozone compared to NCF and CF was 21% and 35.99%, respectively. The results indicate the concomitant relationship between increasing O_3 concentration and decreasing total pods /plant.

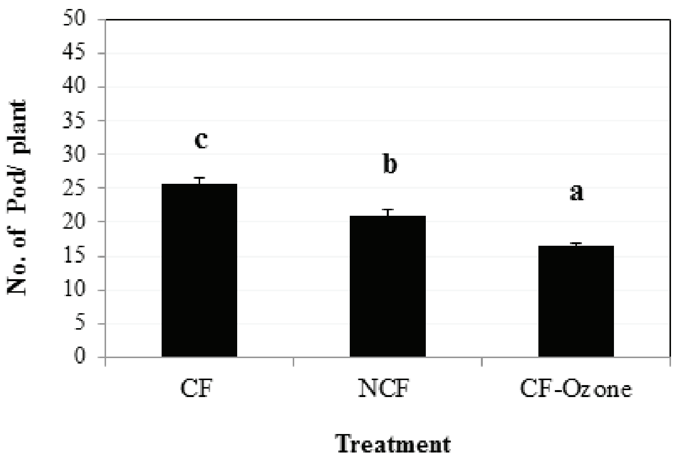

Figure 2: Effects of O_3 concentrations on yield (filled pod/plant) of soybean. The different letters indicate a significant difference at r≤0.05 amongst the treatments. Error bars indicate standard deviations

Fatty acid content: The effects of O_3 on important fatty acid such as oleic, linoleic and linolenic were also analyzed. Since the decisive parameters that determine the damage of O_3 to soybean will appear in seed formed in the pods, measuring the composition of seeds for important nutrients may be a useful index of damage induced by O_3 exposure.

Effects of O_3 exposure on fatty acid concentration of soybean are shown in Figures 3 to 5. Fatty acid content was affected by ozone stress. The linoleic acid (Fig. 4) and linolenic acid (Fig. 5.) concentrations were increased by high level of O_3 while no such effect was found for oleic acid (Fig. 3).

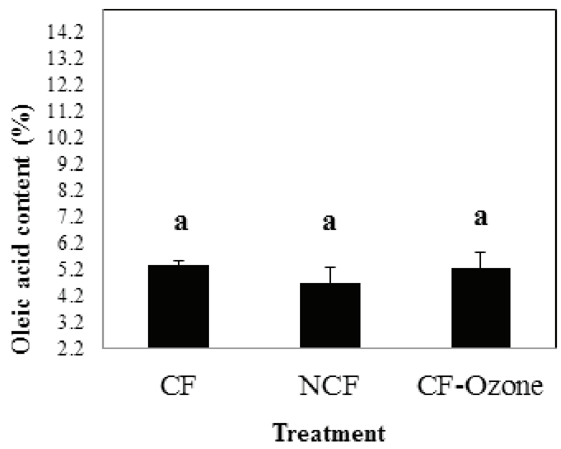

Figure 3: Effects of O_3 concentrations on Oleic content of soybean. The common letters indicate a non-significant difference at r≤0.05 amongst the treatments. Error bars indicate standard deviations.

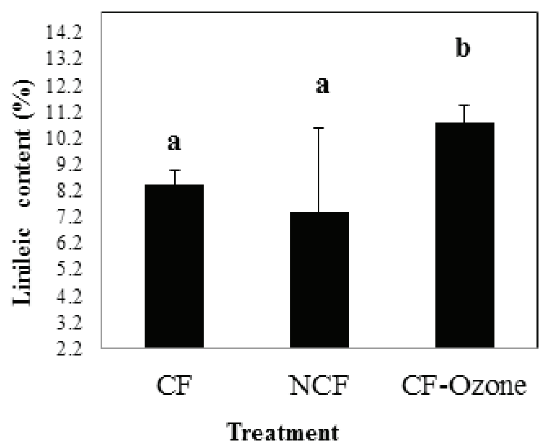

Figure 4: Effects of O_3 concentrations on Oleic content of soybean. The different letters indicate a significant difference at r≤0.05 amongst the treatments. Error bars indicate standard deviations .

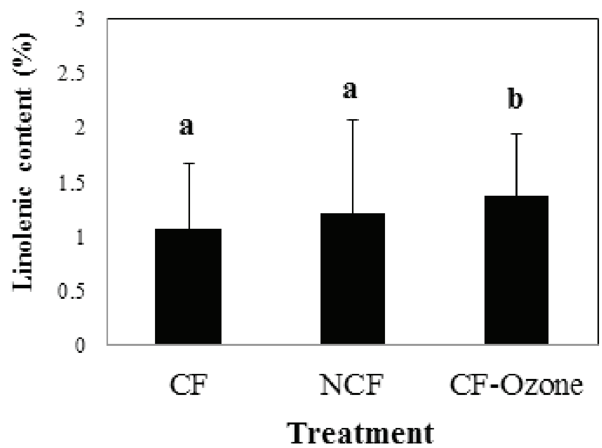

Figure 5: Effects of O_3 concentrations on Oleic content of soybean. The different letters indicate a significant difference at r≤0.05 amongst the treatments. Error bars above indicate standard deviations

The increase in linoleic acid concentration under CF-Ozone treatment was 45% and 27% as compared to NCF and CF, respectively. Linolenic acid content increased by 13.22% and 26% respectively.

The results of this experiment clearly demonstrate strong effects of O_3 on yield of soybean cultivar Chiang Mai 60. We found many consistent results with our investigation. Wahid *et al.* (2001) in Pakistan found reduction in a number of pods/plant rather than in 100 seed weight or number of seed/pod. Kress and Miller (1983) found a great reduction of the numbers of filled pods / plant and 100 seed weight after O_3 exposure. Heagle *et al.* (1986) found the yield loss in soybean by O_3 through reduction in the number of filled pod /plant. Kohut *et al.* (1986) found little effect on pod number, with most of the yield reduction caused by O_3.

The observed effects could be explained by the mechanism of O_3 action on plants. Firstly, Ozone enters the plants mainly through open stoma. Inside the plant, it produces several reactive oxygen species (ROS) such as hydroperoxide (H_2O_2), superoxide ($O_2^{\cdot}$), hydroxyl ($OH^{\cdot}$) and hydroperoxyl ($HOO^{\cdot}$) radicals (Turcsanyi *et al.* 2000). These ROS inhibit the activity of SH-containing, light-activated enzymes of the chloroplast, resulting in the loss of photosynthetic function (Karuppanapandian *et al.* 2011). Reactive oxygen species are able to initiate membrane lipid peroxidation and destruction of cell membranes (Temmerman *et al.* 2002). Ozone reduced the contents of rubisco (in plant leaves), starch and nutrients. O_3 also induced suppression in net carbon exchange rate, water-use efficiency, accelerated reproductive development, and suppressed growth and yield. Exposure of plants to O_3 also usually results in loss of other physiological functions and leads to some loss of nutritional quality (Oksanen and Saeem 1999; Thanacharoenchanaphas and Rugchati 2010).

Ariyaphanphitak *et al.* (2005) describe that the grain growth of cereal is dependent on the production of carbohydrates and the translocation of assimilates from the source organs to the grains. The condition under O_3 exposure may induce the drastic decrease of sucrose content of the internodes, thus storage of assimilates in the culm could induce insufficient photosynthate supply to the grain and protein production. In addition, the various studies showed that O_3, via leaf and cellular constituents, can oxidize nucleic acids, purine and pyrimidine derivatives, amino acid group (Runeckles and Chevone 1992). Bell and Treshow (2002) reported that three amino acid residuals (tryptophan, cysteine, methionin) are particularly sensitive to O_3. They reported that ozonolysis can open up the pyrrol ring of tryptophan and oxidize the sulphydryl group(-SH) of cysteine and methionine to form disulphide bridge(-S-S-) or sulphoxides; alterations in these amino acids will lead to protein reduction in seed.

However, the fact that the elevated O_3 in growing season could induced positive effect on some fatty acid (linoleic and linolenic) is significant. Soybean seeds are the source of protein and oil. The ozone exposure during the growing period of soybean could alter its metabolism. Normally, there is competition between fatty acid and protein contents. The chemical structure of protein is more sensitive to ozone than that of fatty acids. The positive effect on crude and fatty acid of ozone exposure could be explained by the amount and position of double bond. Lipid number of three essential fatty acid in soybean, linoleic, linolenic and oleic, are 18:2(n-6), 18:3(n-3) and18:1 (cis-9) respectively. The ozone oxidation leads to conversion of fatty acid from oleic to linolenic and linoleic acid (Thanacharoenchanaphas and Rugchati 2010). This may explain the positive effect of high level O_3 exposure.

Conclusions

Elevated O_3 concentrations (above ambient level) induced significant suppression in yield as measured by number of pod/plant. However, the concentration of linoleic and linolenic acid was increased significantly. Linoleic content showed more increase than linolenic. The results also showed that soybean planting under O_3 concentration lower than the ambient levels gave best yield. Hence, measures for reducing O_3 concentration are urgently needed.

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Development of management practices to address wheat vulnerability to climate change in North Delta

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Abstract

The effect of using improved agricultural management practices to reduce wheat yield losses under climate change was simulated using CropSyst simulation model. For this experiments were carried out on farmers' fields at El-Serw (Demiatte Governorate) in three growing seasons (2007/08, 2008/09 and 2009/10). Three irrigation treatments were used, i.e. farmer irrigation practice (characterized by large applied irrigation amount), required irrigation amount and irrigation amount applied for raised bed cultivation. CropSyst model was calibrated using data of the 1st growing season then validated using the data of the next two growing seasons. Then, the model was used to simulate the vulnerability of wheat to climate change using two climate change scenarios (A2 and B2) developed by Hadley global climate change model. The results indicated that the highest wheat yield was produced under raised bed cultivation and the lowest under farmer irrigation practice. Furthermore, CropSyst model was able to predict wheat yield with high degree of accuracy for all treatments in both growing seasons. Farmer irrigation practice increased wheat vulnerability to climate change, where the average yield losses were 44-50% under A2 scenario and 41-46% under B2 scenario, averaged over the two seasons, with the lowest water productivity. Lower yield losses were obtained when wheat was irrigated with required amount of water. Raised bed irrigation resulted in even lower yield losses, with the highest water productivity, as a result of better growing environment for wheat plants. These results emphasis the importance of using improved agricultural management practices, which increased wheat yield under current climate condition and will be lowering yield losses under future climate change conditions.

Introduction

Salt affected soils are widely spread in semi-arid and arid areas such as Egypt. Two million feddans (2.5 feddans=1ha) in Egypt are affected by salinization. Some 60% of the cultivated lands of northern Delta region, 20% of the southern Delta and Middle region and 25% of Upper Egypt region are salt affected. Saline soils distribution is closely related to environmental factors such as climate, geology, and geochemical and hydrological conditions. The cropping pattern in Egypt is adjusted to soil conditions. In the northern part of the Nile Delta where soil salinity is somewhat high, crop rotation includes rice and cotton as the main summer crops and wheat and clover as the main winter crops. Both crops exhibit some tolerance to salinity.

Wheat is a very important cereal crop in Egypt, grown widely in different locations. Growing wheat in salt affected soil of El-Serw, Demiatt Governorate is common practice although the yield is reduced compared to that on clay soil. Grain yield of wheat is highly dependent upon the number of spike-bearing tillers produced by each plant (Nerson 1980). The number of productive tillers depends on the environmental conditions present during tiller initiation and subsequent developmental stages. Environmental stress during tiller emergence can inhibit their formation and, at later stages, can cause their abortion. Numerous studies have shown that tiller appearance, abortion, or both are affected by salt stress (Maas and Grieve 1990; Nicolas *et al.* 1993). Soil salinity decreases grain yield of wheat more when plants are stressed prior to booting than later. The yield component affected most by salt stress is the number of spikes produced per plant (Maas and Grieve 1990).

The impact of climate change on soils needs to be considered in parallel with impacts caused by unsustainable land-management practices. In many cases, it is impossible to separate the effects of these impacts; often they interact, leading to a greater cumulative effect on soils than would be predicted from a simple summation of their effects (Brinkman and Sombroek 1993). Where conditions become more arid, salinization and alkalization are likely to increase because evapotranspiration and capillary rise will be enhanced (Fisher 1990). Predicted global warming may give rise to higher evaporation rates, leading to drier soils and more frequent episodes of severe wind erosion. Because arid and semi-arid land ecosystems have little ability to buffer the effects of climate variability relative to most other terrestrial ecosystems, they are particularly vulnerable to climate change and may be among the first ecosystems to be affected by the change (IPCC 2001).

Climate change has the potential to significantly alter the conditions for crop production, with important implications for worldwide food security (Rosenzweig and Hillel 1998). Many studies have documented the effects of climate change on wheat yield in Egypt and concluded that the yield could be reduced by an average of 30% in the Nile Delta and Valley under surface irrigation in old land (Eid *et al.* 1992, 1993, 1994; Khalil *et al*. 2009; Ouda *et al.* 2010). Furthermore, the damage that climate change could do to wheat productivity is expected to be higher in salt affected soils. Changes in yield behavior in relation to shifts in climate can become critical for the economy of farmers. An increasing probability of low returns as a consequence of the more frequent occurrence of adverse conditions could prove dramatic for farmers operating at the limit of economic stress (Torriani *et al*. 2007), especially for farmers cultivating salt affected soil. Under the projected climate change, extra damage is expected to occur to the yield of cultivated crops in these areas as a result of deterioration of the soil.

The objectives of this research were: (i) to calibrate CropSyst model for wheat grown in salt affected soil using one-year field data; (ii) to validate CropSyst model for wheat grown in salt affected soil using two-year field data; (iii) to assess the effect of climate change on wheat grown on salt affected soil; and (iv) to assess the effect using improved agricultural management practices on reducing yield losses under climate change conditions.

Material and methods

Field trials: Trials on farmers field were carried out in the 2007/09, 2008/09 and 2009/10 growing seasons, under the joint ARC- ICARDA Benchmark project. Three irrigation treatments (farmer traditional irrigation method, irrigation with only the required amount, and irrigation in raised beds irrigation amount) were tested. Representative surface soil samples were collected from every trial for chemical analysis. Recommended P_2O_5 as single super phosphate (15% P_2O_5) was incorporated into the soil before cultivation and recommended K_2O as K_2SO_4 was added at tillering stage. Wheat variety 'Sakha 93' was used. Planting for the first two treatments was on flat basin. For the third treat ment it was on the raised beds, which were able to accommodate 5 lines and and a furrow on each side of the bed for irrigation. At tillering, 50% of the recommended N fertilizer (Urea 46% N) was added before irrigation. Crop water requirements over the growing season were determined from ETo and estimates of crop evaporation rates, expressed as crop coefficient (Kc). Cutthroat flume was used to measure applied irrigation water. At harvest, 5 m^2 area was harvested randomly from every irrigation treatment and plants separated into grain and straw and weighed. Harvest index was calculated from these data.

Soil mechanical and chemical analyses are presented in Table 1 and soil moisture constants in Table 2.

Table 1: Physical and chemical analysis of the experimental site

Farmer	Silt (%)	Clay (%)	pH	Ec	ESP
1	26.43	49.58	8.1	1.9	3.5
2	32.28	48.22	8.3	2.2	3.4
3	28.02	55.46	8.0	3.0	4.9

Table 2: Soil water constants for the experimental site

Farmer	Layer thickness (cm)	Field capacity (% w/w)	Bulk density (g/cm³)	Permanent wilt point (% water)
Farmer 1	0-15	48.49	1.18	26.33
	15-30	44.18	1.20	23.99
	30-45	45.99	1.19	24.98
	45-60	41.90	1.28	22.54
Farmer 2	0-15	47.70	1.21	25.43
	15-30	44.26	1.28	24.04
	30-45	43.81	1.35	23.80
	45-60	42.86	1.49	23.28
Farmer 3	0-15	49.43	1.1	26.45
	15-30	48.58	1.1	26.38
	30-45	47.99	1.13	26.06
	45-60	46.90	1.2	25.47

Days to. tillering, anthesis and physiological maturity were determined. Furthermore, maximum leaf area index was measured. All these measurements were used to check how accurate the CropSyst model will be in predicting the final wheat yield.

CropSyst model: The CropSyst (Cropping Systems Simulation Model) objective is to serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and pesticide fate. These are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, variety selection, irrigation, nitrogen fertilization, pesticide applications, soil and irrigation water salinity, tillage operations, and residue management.

The water budget in the model includes rainfall, irrigation, runoff, interception, water infiltration and redistribution in the soil profile, crop transpiration, and evaporation. The nitrogen budget in CropSyst includes nitrogen application, nitrogen transport, nitrogen transformations, ammonium absorption and crop nitrogen uptake. The calculation of daily crop growth, expressed as biomass increase per unit area, is based on a minimum of four limiting factors, namely light, temperature, water, and nitrogen. Pala et al. (1996) suggested that minor adjustments of some of these parameters, accounting for cultivar-specific differences, are desirable whenever suitable experimental information is available. Details on the technical aspects and use of the CropSyst model have been reported elsewhere (Stockle *et al.* 1994; Stockle and Nelson 1994).

Model calibration: Field data for the trial conducting in 2007/08 was used to calibrate the model. The input files required for El-Serw location and wheat crop were prepared and used to run the model. For each farmer, one management file was prepared representing each irrigation treatment. The date of each phenological stage was used to calculate growing degree days for that stage. Total biomass, grain yield, and total and seasonal evapotranspiration were also used for model calibration. The values of the crop input parameters were either taken from the CropSyst manual (Stockle and Nelson 1994) or set to the values observed in the trials. The calibration consisted of slight adjustments of selected crop input parameters to reflect reasonable simulations. These adjustments were around values that were either typical for the crop species or known from previous experiences with the model.

CropSyst validation: The model was validated using the parameters developed in the calibration process for 2008/09 and 2009/10 growing seasons. To test the goodness of fit between the measured and predicted data, percent difference between measured and predicted values for grain yield and biological yield in each growing season were calculated, in addition to the root mean squared error (RMSE) according to Jamieson et al. (1998). Furthermore, Willmott index (WI) of agreement was calculated, which take a value between 0.0 and 1.0; where 1.0 means perfect fit (Willmott 1981).

Climate change scenarios: In this work, the HadCM3, which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre for Climate Prediction and Research (United Kingdom), was used (Gordon *et al*. 2000 and Pope *et al.* 2000) and considered as significantly more sophisticated than earlier versions (Hulme and Jenkins 1998). This model has a spatial resolution of 2.5 x 3.75 (latitude by longitude). HadCM3 provides information about climate change all over the world during the 21st century and presenst information about three times slices: 2020s, 2050s, and 2080s. In order to provide information on possible changes in the world climate, the climate change models are forced to consider future scenarios.

The IPCC (Nakicenvic *et al.* 2000) has developed emission scenarios known as SRES (Special Report on Emission Scenarios). The four SRES scenarios combined two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (IPCC-TGCIA 1999). Two climate change scenarios were considered in this study: A2 and B2. These selected two scenarios consider a rise in global annual mean temperature by 3.1 and 2.2°C, respectively,

Table 3: Measured versus predicted wheat grain and biological yield in for the calibrated field data

Farmer number	Irrigation treatments	Grain yield (ton/ha)			Biological yield (ton/ha)		
		Measured	Predicted	PD (%)	measured	predicted	PD (%)
Farmer 1	I1	6.02	6.01	0.17	17.20	17.18	0.10
	I2	6.62	6.6	0.30	18.39	18.32	0.36
	I3	6.91	6.9	0.14	16.42	16.40	0.13
Farmer 2	I1	6.19	6.16	0.48	17.69	17.59	0.52
	I2	6.45	6.44	0.16	17.92	17.88	0.21
	I3	6.71	6.71	0	15.86	15.85	0.06
Farmer 3	I1	5.60	5.59	0.18	16.00	15.97	0.22
	I2	6.18	6.16	0.32	17.17	17.12	0.27
	I3	6.29	6.26	0.48	11.36	11.29	0.66
RMSE WI		0.62 0.97			0.59 0.96		

Where: PD% = percentage of difference; RMSE = root mean square error; WI= Willmotte index of agreement.

CO_2 concentration 834 and 601 ppmv, respectively, and global mean sea level rise 62 and 52 cm, respectively. As the resolution of the model is too big, using simple interpolation techniques of these percentages have been applied to fit the station site. Data were downloaded in GRIB format from the IPCC Data Distribution Centre web site, and the GRBCONV program source code is found at the following web site: [http://www/dkrz.de/ipcc/ddc/html/HadleyCM3/hadcm3. html].

The GRBCONV program was used to convert the data files from GRIB format to the more conventional ASCII. The download site does not offer the option to subset the data based on an area of interest, so a custom program was used to extract the data for the region of interest. HadCM3 variables were monthly precipitation, solar radiation, and minimum and maximum temperatures. A2 and B2 climate change scenarios were used to run the CropSyst model to predict wheat grain and yield biological in the year of 2050s. The effect of climate change on each of the two growing season will be discussed separately as if each season could be a representation of the growing season of the year of 2050s.

Water productivity: Water productivity was calculated for wheat cultivars under the three irrigation treatments. Furthermore, it was calculated under climate change scenarios and under using the new irrigation schedule. Water productivity (WP, kg/mm) values were calculated by the following equation (Pala *et al.* 1996): WP = Grain yield (kg)/Irrigation amount (mm).

Results and discussion

CropSyst model calibration

The results in Table 3 showed good agreement between measured and predicted grain and biological yield of wheat. The difference between measured and predicted values was less than

Table 4: Measured versus predicted wheat grain and biological yield in the first growing season.

Farmer number	Irrigation treatments	Grain yield (ton/ha)			Biological yield (ton/ha)		
		Measured	Predicted	PD (%)	measured	predicted	PD (%)
Farmer 1	I1	6.25	6.21	0.64	17.85	17.74	0.61
	I2	6.79	6.78	0.15	18.86	18.84	0.12
	I3	7.27	7.20	0.96	20.19	20.01	0.92
Farmer 2	I1	6.02	6.00	0.33	17.20	17.13	0.40
	I2	6.62	6.61	0.15	18.39	18.36	0.18
	I3	6.63	6.61	0.30	18.36	18.36	0.03
Farmer 3	I1	5.6	5.55	0.89	16.00	15.85	0.92
	I2	6.18	6.15	0.49	17.17	17.15	0.09
	I3	6.53	6.50	0.46	16.47	16.43	0.25
RMSE WI		0.45 0.98			0.40 0.97		

Table 5: Measured versus predicted wheat grain and biological yield in the second growing season.

Farmer number	Irrigation treatments	Grain yield (ton/ha)			Biological yield (ton/ha)		
		Measured	Predicted	PD (%)	measured	predicted	PD (%)
Farmer 1	I1	6.00	5.99	0.17	17.14	17.12	0.13
	I2	6.23	6.21	0.32	17.31	17.247	0.34
	I3	5.27	5.26	0.19	11.86	11.835	0.22
Farmer 2	I1	6.01	6.00	0.17	17.17	17.14	0.18
	I2	6.42	6.41	0.16	17.83	17.81	0.11
	I3	6.52	6.50	0.31	17.00	16.96	0.26
Farmer 3	I1	6.08	6.06	0.33	17.37	17.326	0.26
	I2	6.04	6.04	0.00	16.78	16.771	0.04
	I3	6.34	6.33	0.16	12.06	12.018	0.31
RMSE WI		0.55 0.97			0.53 0.97		

1% for both grain and biological yield. Root mean square error was 0.62 and 0.59 ton/ha for grain and biological yield, respectively. Willmotte index (WI) of agreement was 0.97 and 0.96 for grain and biological yield, respectively.

Several publications have highlighted the accuracy of the model, such as Benli *et al.* (2007) and Ouda *et al.* (2010). Both papers indicated that the model prediction showed low RMSE. Benli *et al.* (2007) stated that high Willmott index of agreement was obtained with a value of 0.98, which is similar to what is shown in Table 3. Furthermore, Ouda *et al.* (2010) reported that CropSyst model performance was highly acceptable, where RMSE was 0.137 and 0.026 ton/ha between measured and predicted wheat grain and biological yield, respectively. WI was 0.986 and 0.972 for wheat grain and biological yield, respectively.

Table 6: Effect of different agricultural management practices on wheat grain yield under climate change scenarios in the first growing season.

Farmers number	Irrigation	A2 (%) reduction	A2 (%) improvement	B2 (%) reduction	B2 (%) improvement
Farmer 1	I1	43	--	40	--
	I2	38	5	34	6
	I3	34	9	30	10
Farmer 2	I1	45	--	44	--
	I2	41	4	39	5
	I3	38	7	37	7
Farmer 3	I1	49	--	44	--
	I2	47	2	41	2
	I3	43	6	37	7

Where: A2 and B2 climate change scenarios.

Table 7: Effect of different agricultural management practices on wheat grain yield under climate change scenarios in the second growing season.

Farmers number	Irrigation	A2 (%) reduction	A2 (%) improvement	B2 (%) reduction	B2 (%) improvement
Farmer 1	I1	46	--	41	--
	I2	40	6	35	6
	I3	37	9	31	10
Farmer 2	I1	49	--	47	--
	I2	44	5	42	5
	I3	42	7	36	9
Farmer 3	I1	51	--	49	--
	I2	47	4	45	4
	I3	45	6	41	8

CropSyst model validation

Wheat grain yield: Under Demiatte agro-climatic conditions, CropSyst model performance was highly acceptable, where RMSE was 0.45 and 0.40 ton/ha between measured and predicted grain and biological yield, respectively. WI was 0.98 and 0.97 for grain and biological yield, respectively (Table 4). Singh *et al.* (2008) indicated that CropSyst model is more appropriate than CERES-Wheat in predicting growth and yield of wheat under different N and irrigation application situations, with RMSE equal to 0.36 ton/ha compared with 0.63 ton/ha for CERES-Wheat. Whereas, Lobell and Ortiz-Monasterio (2006) stated that CERES-Wheat model was able to predict wheat yield for different irrigation trials quite well with a RMSE of 0.23 ton/ha.

Table 8: Loss in water productivity (kg/mm) under climate change scenarios in the first growing season

			A2		B2	
Farmer number	**Irrigation treatments**	**WP (current climate)**	**WP (climate change)**	**PR %**	**WP (climate change)**	**PR %**
Farmer 1	I1	9.33	5.32	43	4.81	48
	I2	10.92	6.77	38	5.89	46
	I3	12.40	8.18	34	7.77	37
Farmer 2	I1	8.59	4.38	49	5.60	35
	I2	9.99	5.49	45	7.10	29
	I3	12.33	7.15	42	8.55	31
Farmer 3	I1	7.67	3.84	50	4.30	44
	I2	9.06	4.71	48	5.26	42
	I3	11.13	6.23	44	6.79	33

Where: WP= water productivity (kg/mm); PR%= percentage of reduction.

Table 9: Loss in water productivity (kg/mm) under climate change scenarios in the second growing season.

			A2		B2	
Farmer number	**Irrigation treatments**	**WP (current climate)**	**WP (climate change)**	**PR %**	**WP (climate change)**	**PR %**
Farmer 1	I1	8.26	4.46	46	4.87	41
	I2	8.76	5.26	40	5.70	35
	I3	8.83	5.56	37	6.09	15
Farmer 2	I1	8.57	3.86	55	4.20	51
	I2	10.94	6.77	38	5.10	53
	I3	12.40	8.18	34	6.44	48
Farmer 3	I1	10.19	4.38	57	4.59	55
	I2	10.65	5.00	53	5.22	51
	I3	13.76	6.74	51	7.43	21

Similar trend was observed in the second growing season, where the performance of the model was also highly acceptable. RMSE was 0.55 and 0.53 ton/ha between measured and predicted grain and biological yield, respectively. WI was 0.97 for both grain and biological yield (Table 5). Khalil *et al.* (2009) reported that CropSyst model predicted wheat grain and biological yield in Middle Egypt very well with RMSE equal 0.0157 and 0.1907 ton/ha for grain and biological yield, respectively. They also stated that WI was 0.9899 for both grain and biological yield.

Our results showed that CropSyst model is cable of predicting grain and biological yield of wheat grown in salt-affected soil under the Egyptian conditions (Tables 4 and 5). One of the benefits of using CropSyst model is that it can give an insight to processes happened during the growing season of wheat, which was difficult to measure in the field. The good agreement between measured and predicted values of wheat grain and biological yield implied that the model worked sufficiently well to warrant the exploration of the effect of climate change scenarios.

Effect of climate change

One of the climate change adverse effects is warmer temperatures and increasing episodes of very hot weather. Therefore, it is expected that climate change will have implications for possible fluctuation on wheat yield. The results in Table 6 showed that reduction in wheat yield under A2 climate change scenario was higher than the reduction under B2 climate change scenario, which implied that B2 is less stressful than A2. The highest percentage of yield reduction was obtained for farmer irrigation, followed by application of required irrigation amount and raised-bed irrigation for both climate change scenarios. The results in Table 6 also implied that wheat yield losses was reduced under raised-bed irrigation amount by 9, 7 and 6% for farmer 1, 2 and 3, respectively under A2 climate change scenario, whereas, the reduction was 10, 7 and 7% respectively under B2 climate change scenario.. The results also showed that yield losses increased with increase of Ec value of the soil; the EC value for soil of farmer 1 was 1.9 dS/m and for farmer 3 was 3.0 dS/m.

Similar trend was observed in the second growing season, where wheat yield losses were reduced under raised-bed irrigation by 9, 7 and 6% for farmer 1, 2 and 3, respectively under A2 climate change scenario, and 10, 9 and 8% respectively under B2 climate change scenario (Table 7). These results put an emphasis on using improved agricultural management practices to improve growth environment for the plants under current climate and consequently increase the final yield. Under these circumstances, the vulnerability of the plants to climate change will decrease and yield losses will be reduced.

Water productivity

Crop water productivity is a useful indicator for quantifying the impact of irrigation scheduling decisions, with regard to water management (FAO 2003). Achieving greater water productivity has become a challenge for scientists in agriculture. This should include the employment of practices that deliver more accurate amount of water to crops (Tariq *et al.* 2003). The results in Table 8 indicated that water productivity was reduced under both climate change scenarios in the first growing season. However, the reduction was higher under A2 scenario. The decline in water productivity was higher under farmer irrigation and lower under raised-bed irrigation. Furthermore, raised-bed irrigation reduced the loss in water productivity for the three farmers.

Similar trend was observed in the second growing season, where water productivity deterioration under both climate change scenarios was lower for raised-bed irrigation amount treatment (Table 9).

Conclusion

Our results showed that under climate change condition, the reduction in wheat yield grown on salt affected soil could reach on an average to 46% under conventional farmer practice in applying irrigation. Applying required irrigation amount resulted in somewhat lower yield reduction, compared with farmer irrigation practice, i.e. 44%. Cultivation on raised-bed improved the growing environment for plants. As a result of reduction in the amount of irrigation water applied there would have been reduced fertilizer leaching away from root zone and reduced ground water pollution by fertilizers. Reduction in the applied irrigation water reduced the cost of fuel to run the irrigation pump, it reduced the cost of fertilizer and it increased the profit of farmers as a result of higher production. The water productivity decreased under climate change. However, the loss was the lowest under the raised-bed cultivation.

Sustainable land and water management combined with innovative agricultural technologies could mitigate climate change and help poor farmers adapt to its impacts. New knowledge, technology and policy for agriculture have never been more critical, and adaptation strategies must urgently be applied to national and regional development programs. Adopting the agricultural technologies outlined above will substantially increase the yields of smallholders, regardless of climate change. But adopting better 'temperature-adapted' varieties could completely mitigate the climate change effects that result from global warming. We urgently need better policies that support the adoption of agricultural innovation. Not only will these improve the welfare of rural populations now, but they will also do a great deal to mitigate the future impacts of climate change.

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Vulnerability of cotton crop to climate change in salt affected soil

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Abstract

The vulnerably of cotton yield to climate change was simulated using a CropSyst model. Field trails were carried out at El-Serw (Demiatte Governorate) in 2010 and 2011 growing seasons. Three irrigation treatments were used, i.e. farmer's method of irrigation (characterized by large amount of applied irrigation), applying only required amount of irrigation, and irrigation on raised bed cultivation. CropSyst model was calibrated using data of the 1st growing season then validated using the data of the second growing season. Then, the model was used to simulate the vulnerability of cotton to climate change using two climate change scenarios (A2 and B2) developed by Hadley global climate change model. The results indicated that CropSyst model was able to predict cotton yield with high degree of accuracy for all treatments in both growing seasons. The results also pointed out that farmer's irrigation increased cotton vulnerability to climate change, where the average yield losses were 23-28% under A2 climate change, and 17-22% under B2 climate change scenarios, averaged over the two seasons, with the lowest water productivity. Lower yield losses were obtained when cotton was irrigated with irrigation amount applied for raised bed cultivation in both growing seasons. Losses in water productivity were observed under climate change in all irrigation treatments. However, the reduction was higher under farmer's irrigation method as compared with the other two irrigation treatments. These results emphasis the importance of using improved agricultural management practices, which increased cotton yield under current climate condition and will be lowering yield losses under future climate change conditions.

Introduction

Salinity in topsoil and subsoil is one of the major abiotic environmental stresses in crop production (Grewal 2010). Worldwide, soil salinity is becoming a serious threat to agricultural productivity (Cha-um *et al.* 2006). About 20% of the world's cultivated area and nearly half of the world's irrigated lands are affected by salinity (Zhu 2001). Various plant growth and development processes, such as seed germination, seedling growth, flowering and fruiting are adversely affected by salinity, resulting in reduced yield and quality (Jampeetong and Brix 2009; Gorai *et al.* 2010).

Cotton is tolerant to saline conditions with an EC threshold of nearly 8 dS/m (Maas 1986). Tolerance level for cotton is the average for the growing season. Yield reductions with adult cotton begin at 5.1 dS/m ECw, but as little as 1.0 dS/m can affect seedlings in moderate to slow draining soils. This type of tolerance has been the background for the exploitation of various water resources such as saline water and reclaimed wastewater for cotton production. Unfortunately, despite extensive research on saline and sodic conditions in water and soil and despite short-term success in managing them, the long term effects of salinity seem detrimental to soil properties and to yield (Sadan 1997). This is especially true in areas with low rainfall and insufficient leaching of salts. Methods for alleviation of salinity and sodium hazards have included soil treatments, drip irrigation systems (Hanson and Bendixen 1995) and augmented water schedules (Meiri and Plaut 1985), changes from flat bed to furrow irrigation (Choudhry *et al.* 1994) and varietal selection (Munk and Wroble 1995).

The impact of climate change on soils needs to be considered in parallel with impacts caused by unsustainable land-management practices. In many cases, it is impossible to separate the effects of these impacts; often they interact, leading to a greater cumulative effect on soils than would be predicted from a simple summation of their effects (Brinkman and Sombroek 1993). Predicted warming may give rise to higher evaporation rates, leading to drier soils and more frequent episodes of severe wind erosion. Because arid and semi-arid land ecosystems have little ability to buffer the effects of climate variability relative to most other terrestrial ecosystems, they are particularly vulnerable to climate change and may be among the first ecosystems to be affected by global environmental change (IPCC 2001).

A few researchers in Egypt studied the effect of climate change on cotton (Eid *et al.* 1996, 1997). These studies were conducted on cotton grown in clay soil. However, no research on the effect of climate change was made for cotton grown in salt affected soil. The objectives of this research were: (i) to calibrate CropSyst model for cotton grown in salt affected soil using one-year field data; (ii) to validate CropSyst model for cotton grown in salt affected soil using one-year field data; (iii) to assess the effect of climate change on cotton grown on salt affected soil.

Material and methods

The field trials: Trials were carried out at farmer's field in the 2010 and 2011 growing seasons. Three irrigation treatments (farmer's traditional irrigation on flat basin, irrigation with only required amount of water on flat basin, and irrigation on raised bed/ furrow system), which delivered three different quantities of water, were tested. Representative surface soil samples were collected from every trial for chemical analysis. Planting for the first two treatments was done on flat basin. In case of raised bed system, cotton seeds were planted on both sides of the furrows. Sufficient NPK was applied to insure optimum plants growth. Irrigation was applied according to governmental enforced irrigation intervals. Soil moisture sampling was cdone before irrigation to calculate the needed amount of applied irrigation water to reach field capacity. Water consumptive use was calculated using the following equation (Israelsen and Hansen 1962):

$$CU = (\Theta_2 - \Theta_1) * Bd * ERZ \qquad (1)$$

where: CU=the amount of consumptive use (mm), Θ_2=soil moisture percentage after irrigation, Θ_1=soil moisture percentage before the following irrigation, Bd=bulk density (g/cm^3) and ERZ= effective root zone. Crop water requirements over the growing season were determined from ETo and estimates of crop evaporation rates, expressed as crop coefficient (Kc). Cutthroat flume was used to measure applied irrigation water. Soil contained 26.43% silt and 49.58% clay. The pH was 8.1 and the EC was 1.9 and ESP 3.5%. Soil moisture constants of the soil of each of the two farmers were measured (Table 1).

Table 1: Soil water constants for the experimental sites

Layer thickness (cm)	Field capacity (% ,w/w)	Bulk density (g/cm^3)	Permanent wilt point (% ,water)
0-15	48.49	1.18	26.33
15-30	44.18	1.20	23.99
30-45	45.99	1.19	24.98
45-60	41.90	1.28	22.54

CropSyst model: The details of CropSyst Model have already been presented in this volume by Nor El- Din et al. (2013). Field data for the trial conducting in 2010 was used to calibrate the model. The input file was prepared for each irrigation treatment. The date of each phenological stage was used to calculate growing degree days for that stage. Total biomass, seed cotton yield, and total and seasonal evapotranspiration were also used for model calibration. The model was validated using the parameters developed in the calibration process for 2010 growing seasons, to predict the yield and water consumptive use of 2011. To test the goodness of fit between the measured and predicted data same procedure was used as described by Nor El-Din et al. (2013) in this volume.

Climate change scenarios: In this work, the HadCM3 model was used as already described by Nor El-Din *et al.* (2013) in this volume and same two climate change scenarios were considered (A2 and B2). These selected two scenarios consider a rise in global annual mean temperature by 3.1 and 2.2°C, respectively, CO_2 concentration 834 and 601 ppmv, respectively and global mean sea level rise 62 and 52 cm, respectively. The effect of climate change on each of the two growing season will be discussed separately as if each season could be a representation of the growing season of the year of 2050s.

Water productivity: Water productivity was calculated for cotton under the three irrigation treatments. by the following equation: WP = Seeds yield (kg)/Irrigation amount (mm).

Results and discussion

CropSyst model calibration

Seed cotton and biological yield: The results (Table 2) showed the good agreement between measured and predicted seed cotton and biological yield of cotton. The percentage of difference between measured and predicted values was less than 2% for both. Root mean square error was 0.52 and 0.55 ton/ha for seed and biological yield, respectively. Willmotte index (WI) of agreement was 0.97 and 0.96 for seeds and biological yield, respectively.

Table 2: Measured versus predicted cotton seeds and biological yield for calibrated experiment

Irrigation treatments	Seed cotton yield (ton/ha)			Biological yield (ton/ha)		
	Measured	Predicted	PD %	measured	predicted	PD%
I1	2.40	2.36	1.83	6.00	5.89	1.80
I2	3.20	3.17	1.00	8.00	7.92	1.02
I3	2.57	2.56	0.39	6.43	6.40	0.37
RMSE	0.52			0.55		
WI	0.97			0.96		

PD% = percentage of difference; RMSE = root mean square error; WI= Willmotte index of agreement.

Water consumptive use: The model prediction of water consumptive use was close to the measured values (Table 3). Asare *et al.* (1992) reported that IRRSCH model, which is a simple water balance model, is superior to COTTAM and GOSSYM in approximating crop water stress index at water stress levels most encountered in irrigated fields (−0.15 and −0.40 MPa) and best approximates field water balance.

Table 3: Measured versus predicted cotton water consumptive use for the calibrated field data

Irrigation treatments	Water consumptive use (mm)		
	Measured	Predicted	PD %
I1	635.00	626.70	1.31
I2	603.00	602.80	0.03
I3	585.00	562.20	3.90
RMSE WI	1.82 0.96		

CropSyst model validation

Cotton seeds and biological yield: Under Demiatte agro-climatic conditions, CropSyst model performance was highly acceptable, where RMSE was 0.45 and 0.40 ton/ha between measured and predicted seeds and biological yield, respectively. WI was 0.98 and 0.97 for seeds and biological yield, respectively (Table 4).

Table 4: Measured versus predicted cotton seeds and biological yield in the first growing season

Irrigation treatments	Seed cotton yield (ton/ha)			Biological yield (ton/ha)		
	Measured	Predicted	PD %	Measured	Predicted	PD%
I1	2.70	2.70	0.11	6.750	6.74	0.11
I2	3.70	3.67	0.84	9.250	9.17	0.84
I3	3.61	3.60	0.33	9.025	9.00	0.33
RMSE WI	0.45 0.98			0.40 0.97		

Water consumptive use: A good agreement between measured and predicted values was observed for water consumptive use. Percentage of difference between measured and predicted yield was less than 1% (Table 5).

Table 5: Measured versus predicted cotton water consumptive use for the calibrated field data

Irrigation treatments	Water consumptive use (mm)		
	Measured	Predicted	PD %
I1	612.00	606.90	0.83
I2	595.00	594.20	0.13
I3	576.00	575.00	0.17
RMSE WI	1.67 0.98		

Wang *et al.* (2001) built a cotton production management system (MSCP) based on the validated CottonPlus simulation model. By applying the techniques of crop simulation model and knowledge on engineering, MSCP can conduct the decision-making for optimal multi-objectives, optimal cultivation for all growth season and decision-making for production on time.

Our results showed that CropSyst model was capable of predicting seed and biological yield, in addition to water consumptive use of cotton grown in salt-affected soil under the Egyptian conditions. The good agreement between measured and predicted values of seed cotton and biological yield implied that the model worked sufficiently well to warrant the exploration of the effect of climate change scenarios.

Effect of climate change on crop productivity

One of the climate change adverse effects is warmer temperatures and increasing episodes of very hot weather. Therefore, it is expected that climate change will alter growth conditions for cotton, which will be reflected on final yield. The results in Table 6 showed that reduction in cotton yield under A2 climate change scenario was higher than the reduction under B2 climate change scenario, which implied that B2 is less stressful than A2. The highest percentage of yield reduction was obtained for farmer irrigation practice, followed by application of required amount of irrigation and raised-bed irrigation for both climate change scenarios. The results in Table 6 also implied that raised-bed irrigation reduced cotton yield losses by 18 and 23% for A2 and B2 climate change scenario, respectively compared to farmer irrigation amount. Whereas, in the second growing season, raised-bed irrigation reduced cotton yield losses by 24 and 25% for A2 and B2 climate change scenario, respectively compared to farmer irrigation amount.

Table 6: Percentage of yield reduction in seed cotton yield under climate change scenarios

Irrigation treatments	A2		B2	
	% reduction	% improvement over farmer's practice	% reduction	% improvement over farmer's practice
1st season				
I1	28	--	22	--
I2	25	11	20	9
I3	23	18	17	23
2nd season				
I1	29	--	24	--
I2	25	14	21	13
I3	22	24	18	25

Reddy *et al.* (2002) concluded that cotton yield in the Mississippi Delta in USA might decrease by 9% under climate change conditions. The rate of plant growth and development would behigher in the future because of enhanced metabolic rates at higher temperatures combined with increased carbon availability because of raised carbodioxide concentrations. They also stated that since most of the days with average temperatures above 32°C will likely occur during the reproductive phase, irrigation will be needed to satisfy the high water demand, and this would reduce boll abscission by lowering canopy temperatures. Gwimbi (2009), however, reported that cotton production levels in Gokwe District (Zimbabwe) will decline as precipitation would decrease and temperatures increase under climate change conditions.These results highlight the importance of improved agricultural management practices in reducing the vulnerability of the plants to climate change and decreasing the yield losses.

Water productivity

The results in Table 7 indicated that water productivity was reduced under both climate change scenarios in the both growing seasons. However, the reduction was higher under A2 scenario. The decline in water productivity was higher under farmer's irrigation treatment and lower under raised-bed irrigation. Furthermore, raised-bed irrigation amount lowered the deterioration in water productivity.

Table 7: Loss in water productivity (kg/mm) under climate change scenarios

Irrigation treatments	WP (current climate)	A2		B2	
		WP (climate change)	PR %	WP (climate change)	PR %
1st season					
I1	1.87	1.40	25	1.59	15
I2	2.60	2.00	23	2.27	13
I3	2.20	1.74	21	1.93	12
2nd season					
I1	2.18	1.63	25	1.85	15
I2	3.04	2.31	24	2.65	13
I3	3.07	2.36	23	2.73	11

Conclusion

Our results showed that under climate change condition, the reduction in cotton yield grown on salt affected soil could reach an average of 29% under farmer's practice in applying irrigation. Applying required irrigation amount resulted in lower yield reduction, compared with farmer's method. Whereas, cultivation on raised-bed improved the growth environment for plants , reduced fertilizer leaching from root zone and thus ground water pollution by fertilizers. Reduction in the applied irrigation water also reduced cost of production. With increased production, all these benefits contributed to increased profits to farmers. Reduction in yield and water use efficiency because of climate change could partly be reduced by improved management practice of raising cotton on raised beds and furrow irrigation in contrast to the flood irrigation on flat basin traditionally practiced by farmers. Thus, the vulnerability of cotton to climate change can be reduced under saline soil conditions of El-Serw, Demiatte Governorate, Egypt by appropriate crop management.

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Climate change effects on winter wheat yields in cold rainfed region of Islamic Republic of Iran

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Abstract

Wheat is one of the major crops grown in Iran. The total area covered by wheat under rainfed condition is around 4.2 million hectares. Study on rain effects (total amount and distribution) at six cold rainfed agricultural research stations showed that potential yield of winter wheat was 2000-3600 kg ha^{-1} in 2006-2010. By one or two supplementary irrigations, it was increased to more than 4000 kg ha^{-1}. By decreasing rainfall, crop potential yield decreased to less than half (800 kg ha^{-1}).. This showed the crop yield was highly affected by the amount of rainfall and its distribution. Under rainfed and dryland production systems, impacts of rainfall on crop yield is the largest compared with those of other production factors. This study showed that agriculture in the cold highland region of Iran is sensitive to climate fluctuations and would be at risk from global warming. Although uncertainties remain regarding the rate and magnitude of global climate change, results indicate that climate change would cause reductions in regional agricultural production.

Introduction

Weather and climate remain the major, uncontrolled driving forces of agricultural production. They affect every production management practice from seedbed preparation to harvest (Decker 1994). Many modern-day practices also pose risks to the environment (Hollinger 1994); therefore it is important that appropriate management practices be accomplished when weather conditions are favourable. For plant growth, it is not only the total amount of rainfall within the growing season that is important, but also its seasonal distribution, variability, reliability within and between seasons. Rainfall intensity and rate of infiltration into the soil, the soil ability to retain water and the balance between rainfall and evapotranspiration are also important (ECOCROP-1&2 1998).

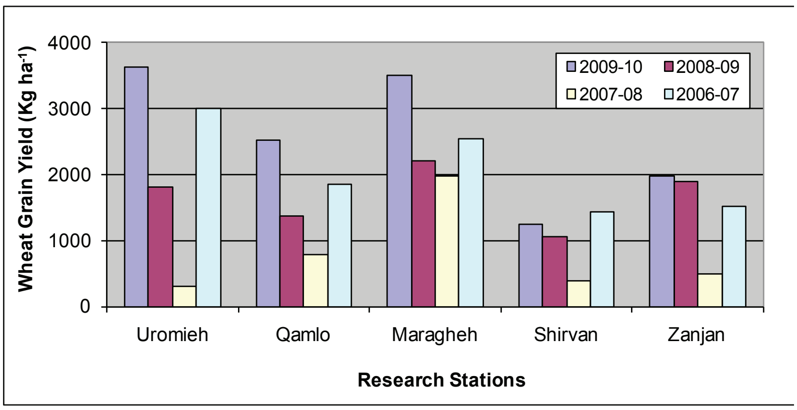

Figure 1: Winter wheat yields during 2006 to 2010 at different rainfed agriculture research stations in Iran.

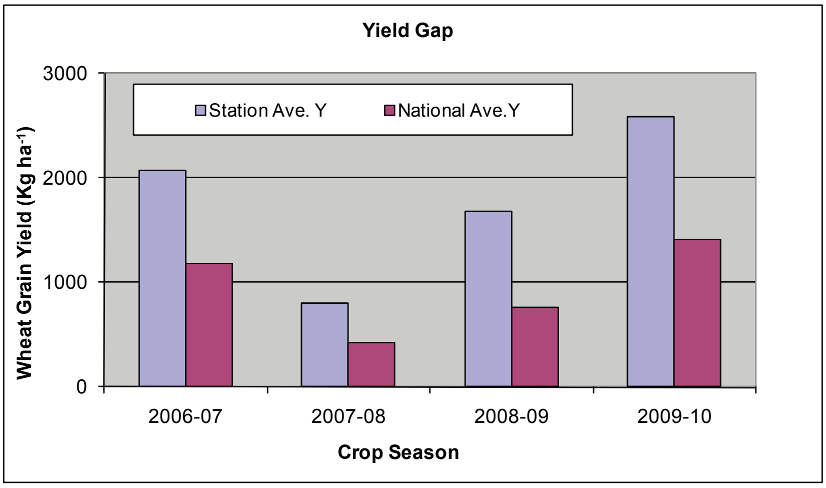

Figure 2: Yield gap for winter wheat between the national average and research station yields, 2006-2010.

Wheat is one of the major crops grown in the Islamic Republic of Iran under both irrigated and rainfed conditions (Anon. 2003). The total area covered by wheat under rainfed condition is around 4.2 million hectares. Irrigated wheat covers one-third of total wheat area but produces over two-third of total wheat production. Average grain yield remains low, due to drought, excessive cold in mountainous areas, and high temperature during late spring in other areas. Average annual precipitation of the country is about 250 mm, with erratic distribution; early drought and terminal drought are predominant.

The dryland areas of Iran, for which the recently established Dryland Agricultural Research Institute (DARI) has a mandate, are characterized by considerable weather variability, as well as major abiotic stresses, in particular drought and cold. During the last two decades DARI has carried out numbers of research projects in different agro-ecological zones to find crop yield potential by appropriate technology (Anon. 2009). The purpose of this paper is to explain the

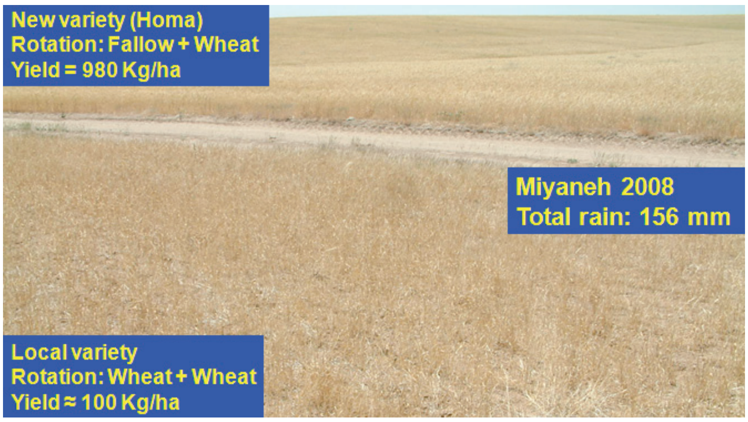

Figure 3: Comparison of the productivity of a new variety of wheat with improved management practice with the productivity of a local variety grown with farmer's own practice in Miyaneh, Iran in 2008 when seasonal precipitation was only 156 mm.

result of such projects and recommended technologies which are adopted over a large area in the dryland farming of country.

Material and methods

A farm survey was conducted in 1995 in East-Azarbaijan (cold environment) and Kermanshah (moderate environment) provinces to reveal factors that hinder crop productivity. Farmers were mainly growing local crop varieties which gave low yields because of the lack of tolerance to biotic and abiotic stresses. There was, therefore, great scope for testing and subsequently disseminating improved crop varieties, along with improved technologies through on-farm verification and demonstration trials.

Long term climate data over 20 years have been collected and analysed to show trends in rainfall. The effect of precipitation on wheat yield was then studied, and the variation interactions between place and year characterized. Finally, the outcome of the last four crop seasons as the representative of normal, dry and wet years is discussed.

Results and discussion

Although, new drought resistance varieties of wheat have been released and farmers have adopted improved technology which helps to achieve sustainabe production, but still crop yield depends on the amount of precipitation, particular in early crop growth stages. Official published crop yield statistics showed that the average winter wheat yield during 2007-2010 were 1180, 420, 760 and 1400 kg ha^{-1} in the country, as compared to 2070, 798, 1669 and 2580 kg ha^{-1} in the research stations, respectively due to rain fluctuations (Figure 1). By one or two supplementary irrigations it was increased to more than 4000 kg ha^{-1} but by a decrease in rain, crop potential yield decreased to less than half (800 kg ha^{-1}). This result showed that there are still big gaps between research station crop yields and the country average levels (Figure 2). In addition, lack of suitable machinery and production technology and dissemination of agricultural information to the farmers, inefficient fertilizer and herbicides use and lack of technologies on water conservation hamper productivity severely in rainfed areas.

In the 2007-2008 growing season with 156 mm rain (one of the driest years in the last 40 years period), recommended technologies resulted in a 300-500% increase in wheat yield (see Figure 3) compared to yields of neighboring farmers using their own technology (0.1-0.3 t/ha in traditional farming and 1-1.5 t/ha in farms with improved technology).

After seeing the crop productivity in the demonstration farms, farmers have widely, adopted the technologies on their own farms. New technology was based on the results of station and on-farm experiments. The participation of farmers, researchers, and extension workers in the testing, demonstration and dissemination of improved technologies has led to better awareness of the technology and to its adoption by a large number of farmers. This will ensure a sustainable increase in wheat productivity in the rainfed areas of Iran. With the adoption of new technologies the production of most crops can be doubled. Appropriate technologies will help in sustainable agricultural production and restrict environmental degradation.

Drought effect should be mitigated for the future through appropriate forecasting methods and management measures. Optimal use of rainfed areas and expansion of supplementary irrigation techniques helps to increase yield in many water available areas.

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Assessment of ecosystem sensitivity and adaptation strategies to desertification and climate change in Lebanon

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Abstract

Lebanon has been affected by changing climatic conditions. Impacts on vegetation was assessed through a systematic overlaying the forest map with current and projected bioclimatic levels. The expected changing parameter was computed for the periods 2020-2044 and 2080-2098. Results confirmed drastic picture in North Lebanon, with a shift in bioclimatic levels from sub-humid to semi-arid.Vulnerability to desertification has been exacerbated in the last four decades through the oscillating rainfall patterns and increasing temperature by 1.8 °C. The primary impact has been well pronounced on water resources; there is an acute decrease in the discharge in rivers and springs, reaching up to 60%, while the groundwater level has abruptly drawn down tens of meters. Also, time series analysis of the normalized differential vegetation index (NDVI) showed an increase in areas affected by higher surface temperature and lower soil humidity reserve creating the situation for recurrent drought incidences. Lebanese soils are vulnerable to erosion processes, witnessing high erosion rates exceeding 70 ton ha-1. This is preconditioning low resilience to drought. Observations have also revealed the mountain shallow Leptosols, Luvisols and Arenosols to be the most vulnerable to fire incidences. In the light of the existing situation, however, adaptation measures have been demonstrated in this study, considering the sensitivity of the Lebanese ecosystem to desertification along with changing climatic conditions. It will serve as first hand information for decision makers in proposing strategies for risk mitigation.

Introduction

Due to a combination of natural and human factors, Mediterranean countries have been undergoing, especially over the last four decades, rapid changes and fast development. Desertification and land degradation have affected most of the arid and semi-arid Mediterranean areas (Christensen *et al.* 2007; ISMEA IAMB 2009; Seguin 2010; Shaban 2011), where the prevailing climatic patterns, social behavior and socio-economic conditions are likely to aggravate significantly this process and to critically undermine the effectiveness of efforts to adapt to climate change. The particular vulnerability of these ecosystems to climate change was often highlighted by the Intergovernmental Panel on Climate Change (IPCC 2007), and others (Giupponi and Shechter 2003; Giannakopoulos *et al.* 2005; NOAA 2011). Unlike most terrestrial ecosystems that posses some kind of built-in ability to buffer against the effects of climate variability, small changes in climate over arid and semi-arid lands can intensify the effects of natural variability and lead to permanent degradation of their potential productivity (Bullock and Le Houérou 1996). Moreover, poverty, political instability, deforestation, overgrazing and bad agricultural practices can further reduce land's productivity (UNINC 1994).

Studies from the Mediterranean region show that the current tree flora is made up of very resilient old taxa that have already experienced many abrupt and intense climate changes in the past, being able to maintain quite stable populations through periods where climate conditions have changed (Hajar *et al.* 2008; Petit *et al.* 2008). However, climate change in the Mediterranean environment is expected to witness a drastic alteration inducing higher variations in temperatures and precipitations. Projections for 2040 foresee a relatively significant increase in summer temperatures along with a noteworthy decrease in precipitation (MoE/GEF/UNDP, 2011). In addition, regional climate models are broadly predicting a hotter, drier and less predictable climate (Kasparek 2012). By the mid of this century, the Middle East region is expected to get hotter across all seasons and models forecast an increase of temperature between 2.5 to 3.7° C in summer, and 2.0 to 3.1° C in winter (IPCC 2007; Brown and Crawford 2009).

As a typical eastern Mediterranean country, Lebanon is threatened by desertification too. The country is moderately to highly sensitive to the process due to several biotic and abiotic factors (Darwish *et al*. 2012), including recurrent drought, forest degradation and overexploitation of natural resources. In addition, the abrupt changes in topography created a striking diversity of climate, soils (Darwish and Zurayk 1997) and vegetation cover (Abi-Saleh and Safi 1988), causing accelerated soil erosion (CoLD 2005). The pressures on limited natural resources have been exacerbated by human interference and land use change (Masri *et al.* 2002; Darwish *et al.* 2010), intensive agriculture (Atallah *et al*. 2000) and overgrazing (Darwish and Faour 2008), rapid population and chaotic urban growth (Huybrechts 1997; Darwish *et al.* 2004) and mismanagement of water resources (El Moujabber *et al.* 2006; Darwish *et al.* 2011). In their turn, poor soil resilience and scarce vegetation cover, decreasing volume of water resources amplified by desertification, have a major impact on the poorest and most vulnerable part of the population. Hence, predicting future hotspots in the context of the anticipated climate, social, economic, and bio-physical changes can help better planning of adaptive measures to alleviate poverty and combat food insecurity (Enne *et al.* 2003; Lambin *et al.* 2009; Reynolds *et al.* 2011).

The predicted changes in temperature and rainfall rates are expected to be accompanied by a significant change in the geographical extent of the bioclimatic levels in Lebanon, in terms of percentage of total cover. Some authors even argue that the Oromediterranean vegetation level will totally disappear from Lebanon by 2080, while the arid bioclimatic level is expected to increase from 5 to 15% in area extension (Abou Samra *et al.* 2009). In such a context, climate change will incur changes in environmental conditions including vegetation and species composition. Thus, it will create threats to biodiversity and forests by causing changes in the composition of the plant and animal communities, variations in the altitudinal limits of natural forests stands (known as species migrations and ability to shift upward or northward), alterations in regeneration patterns and forest structures and higher frequencies of wildfires and pest outbreaks (Awad 2009; Kasparek 2012).

On the other hand, drought globally is a major natural hazard affecting large areas and millions of people every year. According to the IPCC (2007), climate change will lead to a change in the frequency and intensity of droughts across the world. In fact, the most robust conclusions emerged from the climate change assessment report are: (a) an increased probability of extreme warm days and decreased probability of extreme cold days and (b) an increased drought risk for mid-continental areas during summer.

The recent occurrence of prolonged drought conditions in various Arab countries has emphasized the need for adequate monitoring tools of drought events. In fact, changes in climatic conditions are predicted to be particularly severe in the Eastern Mediterranean and the Middle East. This has been assessed in the framework of the Lebanese National Communication report presented to the United Nations Framework Convention on Climate Change (MoE/GEF/UNDP 2011) which sought to investigate the potential application of remotely sensed data, particularly by using sequential MODIS-Terra satellite images in mapping recent droughts in Eastern Mediterranean. The measurements and observations showed increased expansion of dry lands, decreased vegetation cover area and scarcity in water resources: These factors are the major drivers of desertification. Hence, it is important to identify different causal-effect relationships on the territory, to estimate current state of desertification risk patterns and their extent and to adopt action plans and necessary adaptation measures. Based on the above, the objective of this study is to assess the sensitivity of the Lebanese territory to desertification under the changing climatic conditions using updated geo-information data on climate, geomorphology, vegetation cover and soil characteristics.

Materials and methods

Location and characteristics of the study area

Lebanon is located on the eastern shore of the Mediterranean Sea at the intersection between Europe, Asia and Africa, between 33° and 35° N latitudes, and 35° and 37° E longitudes (Fig. 1). It is a predominantly mountainous country with an area of 10,452 km^2 a North-South length of 190 km and a maximum width of 75 km. Like any other mountainous country, Lebanon's physical geography is complex with diverse landform, climate, soils, and vegetation. Moreover, sharp changes in other elements of the environment, from productive to poor soils are observed throughout the Lebanese mountains.

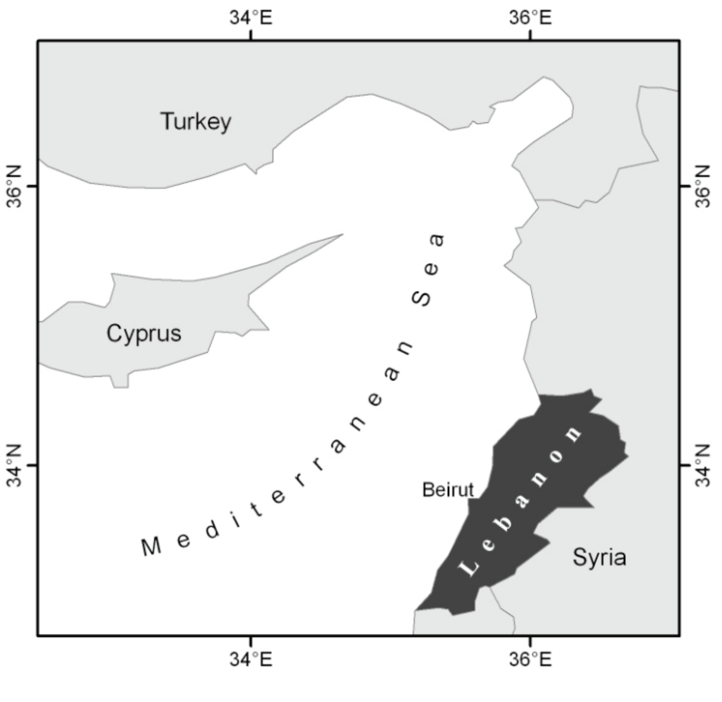


Figure 1: Geographical location of Lebanon.

The Mediterranean climatic zone is specified by the existence of dry periods with various lengths depending on the location around the Mediterranean Sea, which impose annual stress on vegetations (Quézel and Médail 2003). Being on the region's eastern shore, Lebanon is under the influence of the Mediterranean climate with four clearly distinguished seasons: hot and dry summer, cool and rainy winter, and moderately dry fall and spring. The number of annual rainy days varies between 60 and 80 days (Sanlaville 1977). At very high altitudes, varying between 1500m and 3000m, patches of snow cover might remain from 6 to 9 months and rarely, limited small patches stay the year round (Jomaa 2008). January with a mean temperature of 22° C and August with a mean temperature of 30° C are the coldest and the hottest months respectively.

Assessing desertification occurrence and intensity and the related physical processes requires the analysis of a number of parameters which include climate, water, vegetation, and soil, empirically and respectively diagnosed through: 1) statistical analysis and records of interpolation, 2) Normalized Differential Vegetation Index (NDVI) and 3) monitoring soil capacity to water retention. Nevertheless, in analyzing the three components, remotely sensed data acquisition was a fundamental tool as it allowed for geo-spatial information extraction on large area extent and for monitoring analysis purposes.

Assessing climate and water trends

The assessment of climatic and hydrologic trends for long-term time intervals require conventional and advanced tools for data acquisition and analysis. This is particularly important when the availability of data is not complete, such as in the case of Lebanon. For this reason, climatic and hydrologic data sources were utilized in this study:

Hydrologic records: These include datasets on discharges from rivers, springs, lakes, snow cover and groundwater. Therefore, a set of time series data has been gathered from different sources, with a special emphasis to Litani River Authority (LRA) and the Lebanese Agriculture Research Institute (LARI). The collected datasets cover more than fifty years and some are prior to1960s. Consequently, the gaps were filled by overlapping the time series from different sources including the dates and the geographical distribution of data.

In this respect, monitoring the dynamic changes in lakes and snow cover was performed by using satellite images of different spatial and temporal resolution. Major lakes (e.g. Qaraaoun Lake, Shabroh Lake) were observed by Landsat 7 ETM+ (30 m resolution) and this was undertaken for the period from 1982 to date, while for snow cover, the analysis of MODIS and SPOT images with respectively 250 m and 10 m spatial resolution were considered. However, in both cases (i.e. lakes and snow cover), the images were processed using ERDAS Imagine software with a number of spectral and optical advantages.

Rainfall and temperature records: Rainfall and temperature datasets were used from ground stations measurements taken by some governmental institutes, especially the General Directorate of Civil Aviation (GDCA), as well as universities, research centers, etc.

Even though data on average annual temperature were available since 1961, yet there are still many gaps for a miscellany of a couple of years. However, the available time series on temperature were quite sufficient to illustrate trends over the past five decades. Thus, Singular Spectrum

Analysis and Fisher Shannon methods were applied to interpolate the temperature trend which has a number of time gaps. Rainfall data records were also not continuous while the available ones dated back to the period starting in 1955 and lacked any uniform geographic distribution. However, gaps on these records were filled by using remotely sensed data adopted from the Tropical Rainfall Mapping Mission (TRMM) system, introduced by NASA and based on 3-hours measuring from Microwave sensors, providing daily data since 1998.

Assessing drought impact on vegetation cover: The development of earth observation satellites from the 1980s onwards, equipped with sensors mainly in the optical domain, opened a new road for drought monitoring and detection. Numerous indices were developed to describe the state of the land surface, mainly of vegetation, with the potential to detect and monitor anomalies such as droughts. The most prominent vegetation index is certainly the Normalized Difference Vegetation Index NDVI (Tucker 1979) that was first applied to drought monitoring by (Tucker and Choudhury 1987). This study triggered several derivatives for drought monitoring such as the Vegetation Condition Index VCI (Kogan 1995, 1997), represented by the following equation:

$$(VCI = l00*(NDVI - NDVI_{min}) / (NDVI_{max} – NDVI_{min}$$

The VCI ranges between zero for extremely unfavorable conditions and 100 for optimal conditions, where $NDVI_{min}$ and $NDVI_{max}$ refer respectively to the absolute minimum and maximum NDVI measured for a given month over a multi-year series of image data, while NDVI refers to the current year NDVI for the same month. In addition to the information derived from the optical domain, the thermal channels were exploited resulting in the retrieval of land surface temperature estimates (LST), related to water stress conditions in vegetation. Kogan (1995) proposed the Temperature Condition Index (TCI) defined according to the following equation:

$$TCI = l00*(LST_{max} - LST) / (LST_{max} – LST_{min})$$

where TCI is equivalent to VCI but based on Land Surface Temperature (LST).

Most promising was the Vegetation Health Index (VHI) proposed by (Kogan 1997, 2001). Following the above-mentioned hypothesis, Kogan (1995) proposed another index, which is an additive combination of VCI and TCI:

$$VHI= a\ VCI + (1-a)\ TCI$$

where “a” is the relative contribution of VCI and TCI in the VHI.

In most published analyses, “a” has been assigned a value of 0.5, assuming an even contribution from both elements in the combined index. Our study focuses on determining the VHI index which serves to identify drought events.

Assessing the vulnerability of forest cover: In order to assess the expected impacts of climate variability (increase in temperature and decrease in annual rainfall) on vulnerable forest spots in Lebanon, the derived forest map of Lebanon was overlaid on the grid map as well as the bioclimatic levels in Lebanon computed using the Q (Emberger quotient) for each level. This leveling is firmly correlated to bioclimatic conditions deriving from the computation of the “Quotient pluviothermique” (Q) of Emberger:

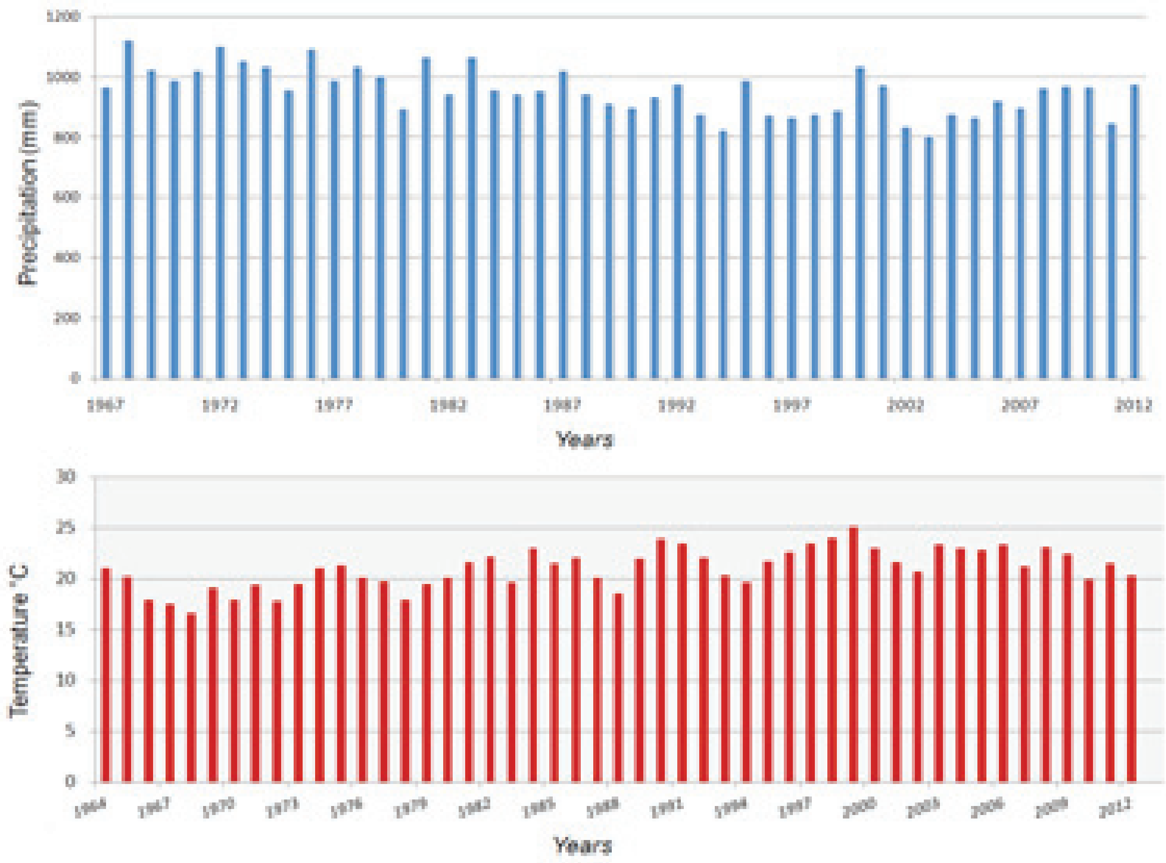


Figure 2: Average annual rainfall and temperature in Lebanon.

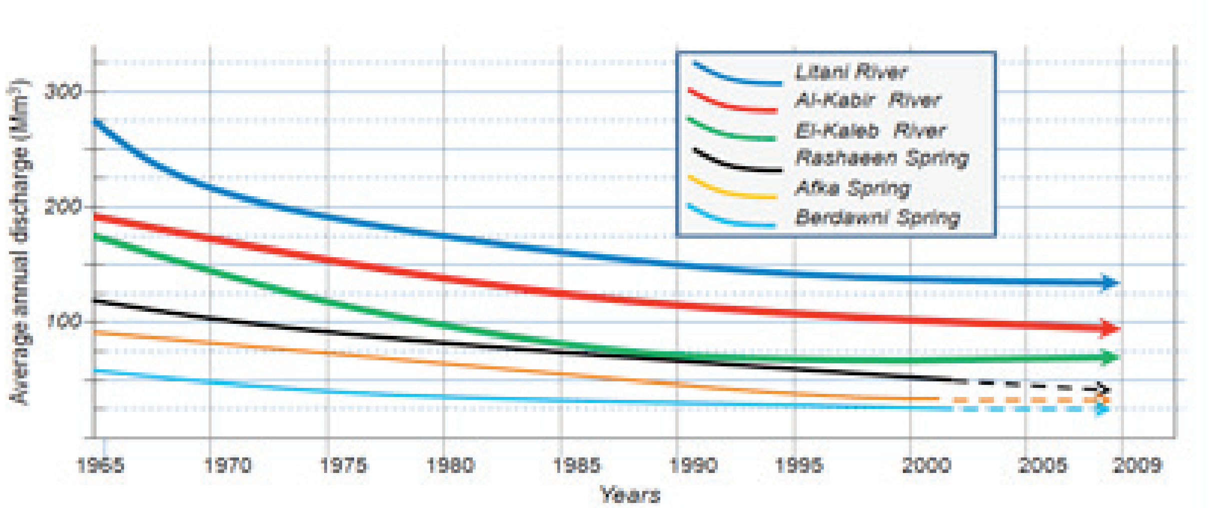
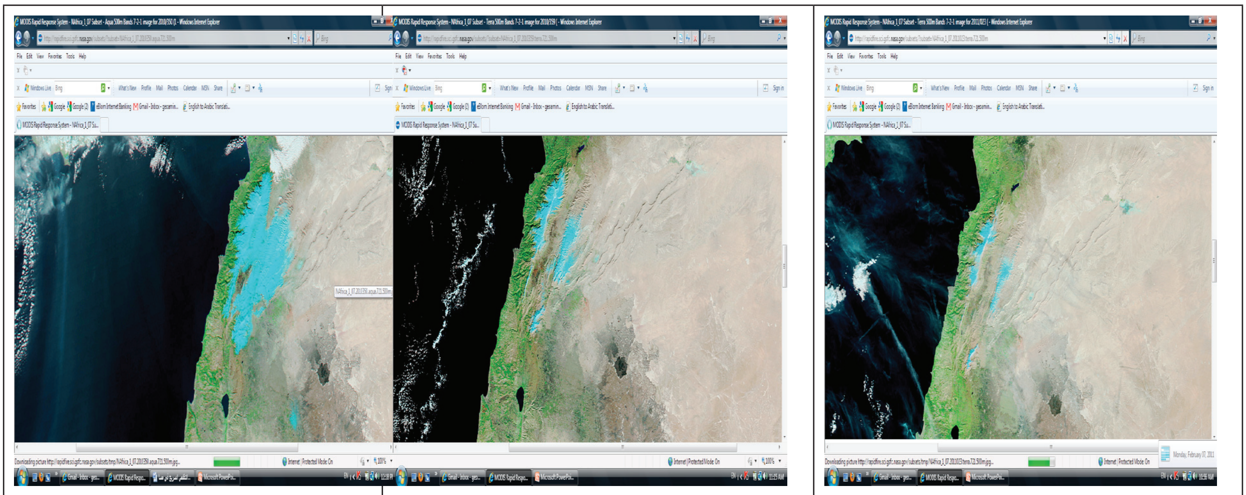


Figure 3: Discharge trends of representative rivers and springs in Lebanon (Shaban 2011).



15/12/2010	25/12/2010	25/01/2011

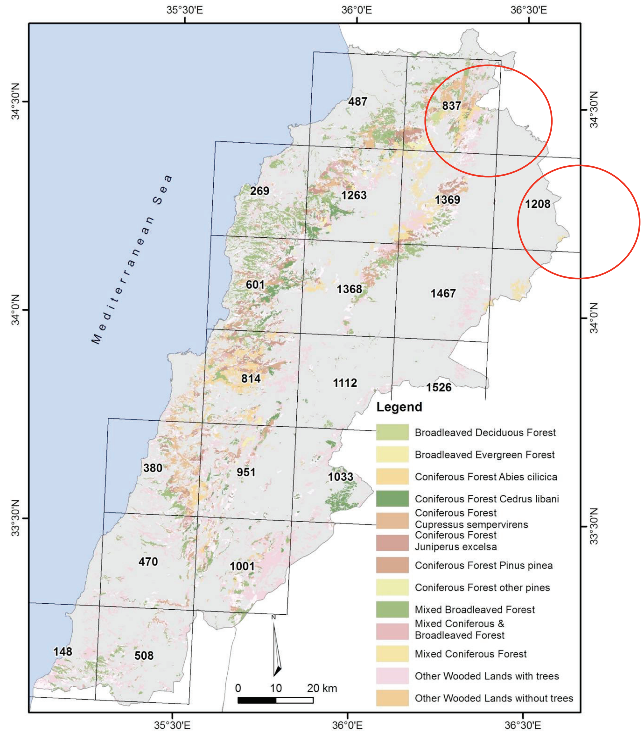
Figure 4: Snow cover area fast reduction by higher temperature events during winter season in Lebanon (MODIS Images (Bands 7-2-1).

$$Q = \frac{1000 \times P}{0.5 \times (M + m) \times (M - m)} \quad \text{Or} \quad Q = 2000P\,(M_2 - m_2)$$

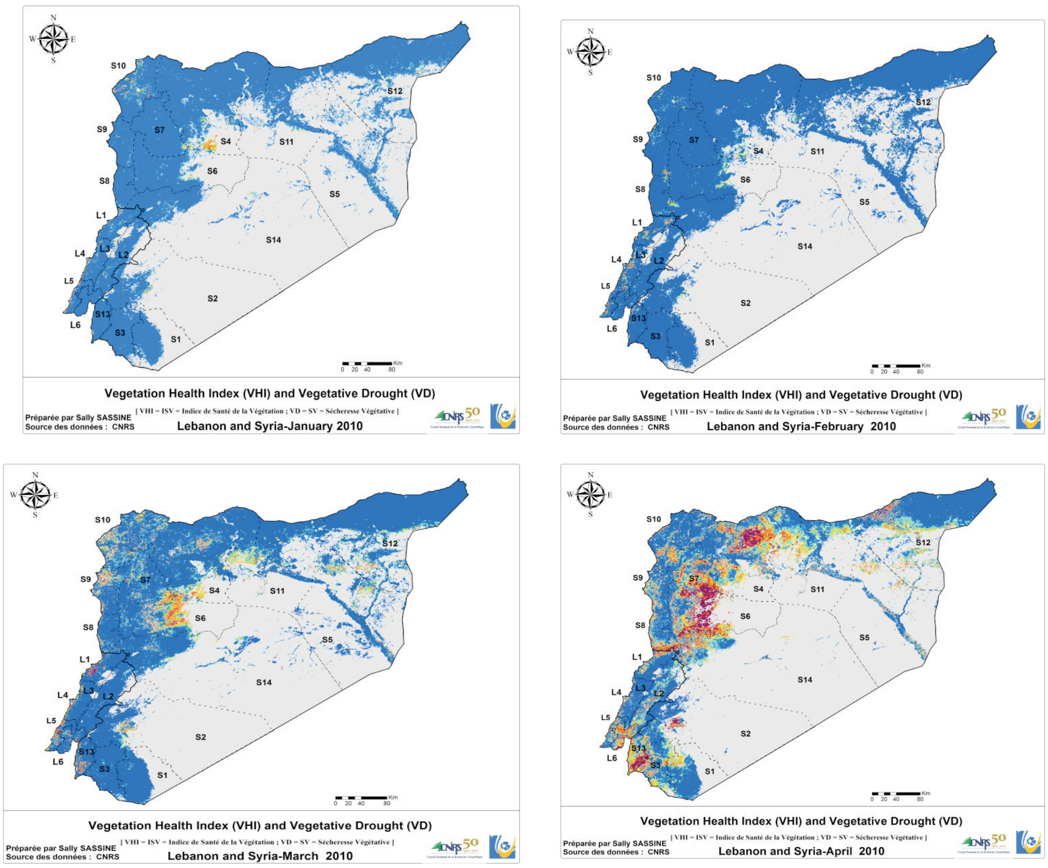
where P is the annual precipitation in mm, M the mean maximum temperature of the hottest month expressed in Kelvin temperature (° K), and m the mean minimum temperature of the coldest month expressed in ° K. Then, for every grid, a Q' (using the P, M, m figures projected for the period from 2020 to 2044) and a Q" (using the P, M, m figures projected for the period from 2080 to 2098) parameter were computed and hence, the grids where the shift in bioclimatic level surpasses the ecological tolerance of the dominant forest type were highlighted. The assessment covered the entire country with focus on forest areas and extended over an entire year, since forest vulnerability depends on both temperature increase (summer) and precipitation (winter). The year 2004 was taken as a baseline year, and projections were made until 2030, i.e., over a time frame of around 25 years.

Assessing soil resilience to drought involving organic carbon stock: **T**he soil and terrain database at 1:50,000 scale available at the CNRS-CRS was used to assess SOC. The impact of forest fires on carbon loss in the upper soil horizon and entire soil profile was assessed based on the SOC density and stock assessment, using information from 450 soil profiles distributed over the national territory. The average soil carbon density (SCD) in a given soil type (ton ha^{-1}) was calculated involving organic matter content (%), bulk density (g/cm^3), thickness (cm) and coarse fragments content (% fragments> 2 mm size) using the following equation:

$$SCD_{site} = \sum_{layer=1}^{j} (SOC_{content} * BulkDensity * Depth * (1 - frag))$$



.**Figure 5:** Areas (circles) expected to be most impacted by climatic factors



.**Figure 6:** Vegetation Health Maps for Lebanon and Syria in January, February, March and April 2010

Results and discussion

State of water resources in view of climatic variability

The changing climatic trends, along with their impact on water resources, and more specifically the decrease in the amount of available water, are one of the major components indicating desertification, and thus influencing other aspects related to water decline (e.g. drought, etc). Accordingly, this study investigated the principal climatic parameters (i.e. rainfall and temperature) by applying different approaches of statistical analysis and data interpolation. The results showed a general decline in precipitation rate by about 50 mm over the last five decades (Fig. 2), accompanied with an obvious increase in the temperature by about 1.8° C (Fig. 3).

The analysis was extended to the fundamental hydrologic parameters; therefore, discharges from rivers and springs as well as snow cover were investigated as surface water components. This applied also to groundwater levels. A sharp decrease in the amount of water discharged from rivers and springs in Lebanon reaching 60% (Shaban 2011) over the last four decades was clearly shown (Fig. 3) while snow cover fluctuated by several peaks, but with a general decline from an average of about 2,450 km^2 to about 2,050 km^2 over the past three decades (Shaban 2011). Snow area reduction was associated with a fast snow melting, observed by MODIS, during the peak time of winter which decreased the area of snow from 2,200 km^2 on 15 December 2010 until 1,700 km^2 ten days later and down to 1,150 km^2 one month later (Fig. 4).

Besides, groundwater is also subjected to an abrupt regression in water yield. This is well pronounced in representative investigated wells in different geographic areas in Lebanon. There is a drawdown in the underground water level of the major two aquifers in Lebanon (i.e. Cenomanian and Jurassic Limestone) estimated at 25 m and 10 m respectively (Shaban 2009, 2011) followed by a sharp decrease, reaching 50% of the discharge from many observed wells dug into these aquifers. Therefore, climate variability and shortage in water resources can profoundly affect ecosystem resilience to drought and forest fires.

Climate change impact on forest and vegetation cover

Results confirmed that if climate change scenarios were to become a reality, this would be have drastic effect in North Lebanon, Akkar and Hermel areas, where the shift in bioclimatic levels from sub-humid to semi-arid might considerably affect forest stands and potentially challenge their survival (Fig. 5).
The Vegetation Health Indicators (VHI) maps at monthly frequency produced using DICE software were classified into 5 classes presenting the status of vegetation: extreme drought (<10%), severe drought (between 10 and 20%), moderate drought (between 20 and 30%), mild drought (between 30 and 40%) and no drought (>40%) as proposed by (Kogan 2001). VHI maps were generated for the period between January 2010 and April 2011 during the peak of vegetation cycle in the region (Fig. 6) and overlaid with the administrative layers to assist in the interpretation of the results. In January 2010, the state of vegetation was very positive in Lebanon, while the month of February recorded severe drought conditions in some regions of the country like Meten, Qoubayat and Koura. In March, The Lebanese coastal zone was affected by a moderate drought and in April, the extreme drought struck surpassing that in March .all over Lebanon leaving 57% of the territory under drought conditions and triggering large forest fires

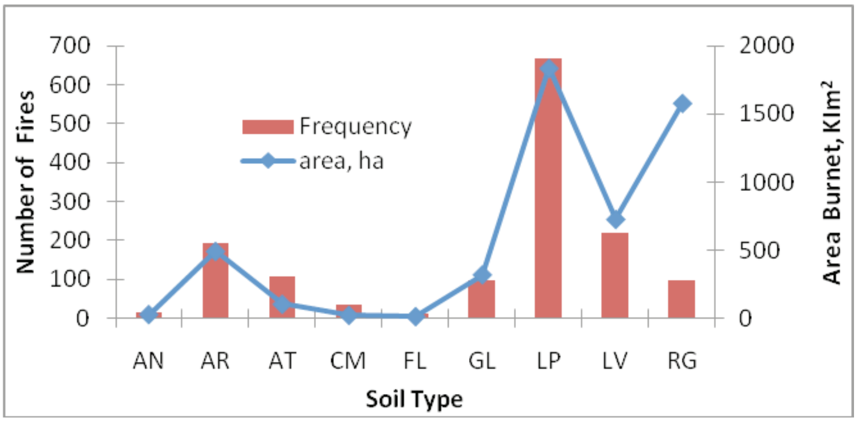


Figure 7: State of fires recurrence between 2003 and 2010 on different soil types in Lebanon.

Soil resilience to drought

Lebanese soils are characterized by relatively poor organic matter content (Darwish *et al.* 2006) and in line with the rest of the soils spread throughout the region (Zdruli 2010, 2012). Measured values in the upper soil horizon showed that Luvisosls are in general richer in OM content compared to Cambisols which contain 54.5 ton/ha and 45.4 ton/ha OM respectively (Table 1). On the other hand, Leptosols, Calcisols, Andosols and Vertisols represented the lowest SOC storage due to their origin, rock-plant interactions and soil physico-chemical properties. Therefore, these soils as well as light textured and highly gravely soils require organic amendment to improve water storage in the soil and vegetation resilience to drought conditions.

Table 1: Organic carbon stock in top horizon for Lebanese soils

Soil type	Mean (T/ha)	SD	Area (Km^2)	Total (Mil. T)
Andosols	35.04	16.2	158.13	**0.55**
Arenosols	49.10	40.16	371.97	**1.83**
Anthrosols	55.42	37.23	426.65	**2.36**
Calcisols	22.86	20.56	321.17	**0.73**
Cambisols	45.10	31.66	971.92	**4.38**
Fluvisols	31.36	23.86	353.79	**1.11**
Gleysols	46.42	52.42	166.1	**0.77**
Leptosols	39.04	37.97	3954.8	**14.88**
Luvisols	54.58	80.75	1328.78	**7.25**
Regosols	28.99	25.13	1193.81	**3.46**
Vertisols	22.82	17.01	73.47	**0.17**
Total	**39.16**	**-**	**9320.59**	**37.50**

At the national level, a total of 1,446 fires occurred between 2003 and 2010 distributed mainly in the central parts of the northern and southern regions and along the western coastal Lebanese mountains. The number of fires were 520 in 2003, 158 in 2005, 652 in 2007 and 116 in 2010, damaging a total forest and cultivated area of 4,518.85 ha, equivalent to 1.25% of national green area. The general trend of fires-soil relationship for the observed years shows more frequent fires on Luvisols and sandy soils (Arenosols) and notably shallow Leptosols distinguished by high erosion rates and enrichment with coarse fragments (Fig. 7). Despite the small number of fires on Regosols, the area burnt is the second by its surface indicating higher vulnerability of vegetation grown on these high gravel soils of slopping lands compared to the sandy Arenosols and clay soil types. Similar soils are characterized by lower water holding capacity as compared to deeper and heavier texture soils like Luvisols, Cambisols, Fluvisols and Gleysols with higher water reserves supporting plant resilience to drought. The burnt area on these soil types in 2003 did not exceed 50 ha while in the first soil group it reached 800 and 1,600 ha respectively.

The combination of forest fires with land cover/land use map showed that the most vulnerable areas to fires are forest (oak and pine) and agriculture lands mixed with urban areas with prevalence of Anthrosols (AT). Farmers' practice of burning the plant residues after harvest triggers fires which expand on to neighboring lands. In general, more frequent forest fires occurred on poor shallow mountain soils with light texture and low water retention capacity and on cultivated soils and mixed urban lands with other uses, like olive orchards and fruit trees

Conclusion and recommendations

Observation on climatic records in Lebanon showed a general decline in precipitation by 50 mm accompanied with an obvious increase in the temperature by about 1.8° over the last five decades. Climate change was also associated with an average reduction in the area of snow cover from 2,450 km^2 to 2,050 km^2 over the past three decades resulting in an abrupt regression in water yield and groundwater level. Climate change can be considered as a threat to forests if current practices of exploitation, grazing and urban encroachment continue. But, it can be also seen as an opportunity to reorient national policies and implement measures to assist the natural resilience of forests to anticipated future change. The results of this study clearly show that the spatial and temporal characteristics of drought in Lebanon and East Mediterranean can be mapped from MODIS data while the VCI images derived from the NDVI time series described very well the past episodes of drought in the area. The TCI index improved the performance of this index by providing more information on water stress and consequently the risk of drought and forest fires. The combinations of these two indices assisted in generating the VHI index with the advantage of the ease of application and open access of MODIS data.

Having investigated the major biophysical elements acting on desertification, adaptation measures can be well identified. This can be done in the framework of a strategic plan to be plotted on the local and regional levels. It should be viewed from four major pillars: climate, water, vegetation and soil. Accordingly, for climate it must be worked on the global view, notably in focusing on GHG mitigation and yield control, and this should be also interrelated to the reservation of vegetation cover as a stabilizing factor for climatic conditions. With respect to water resources, there are a number of adaptation measures that can be implemented, and they can be on small and large scale. These include, in a broad sense, water re-use, harvesting of surface water, artificial recharge, wise and efficient-use of water resources and awareness for water consumers. Implementation of land suitability for specific land use, including urban sprawl, introducing controlled grazing, improving carbon sequestration and enriching the Lebanese soils with organic amendments are crucial to increase organic matter content, improve soil water retention and ecosystem tolerance to drought. These actions could reduce the number and extent of forest fires notably on light and gravely soils and protect the unique ecosystems of Lebanon.

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Some indicators of the effect of global warming on olive tree flowering in south Tunisia

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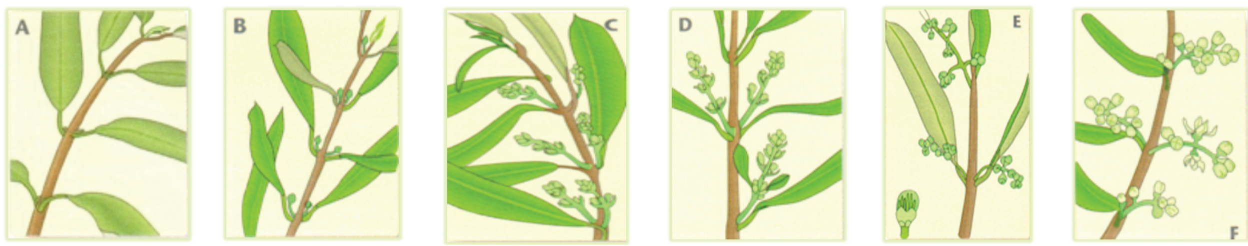
Abstract

Olive tree (*Olea europaea* L.) is the major crop in Tunisia and cultivated from the south to the north of the country. Flowering is considered the most important and delicate phase, and it reflect correctly the environmental extrinsic and tree intrinsic conditions. In the present work we studied the impact of global warming on the olive tree in the south-east Tunisia, where nowadays the future of this crop is suspect. This study focused on the floral phenological observations during 18 years (1992-2009) on three Tunisian olive cultivars (*'Zalmati', 'Chemlali',* and *'Zarrazi'*) in an arid area (Zarzis, 33°36'N; 11°01'E). The annual rainfall during the last decade has shown a trend for reduction while temperature, especially during winter, has shown a trend for increase. The results have shown that this crucial stage of the reproductive stage has varied along the time, depending on the meteorological conditions. Taking into account both phenological and meteorological databases it has been observed that global warming has impacted the flowering period. Along the years, an advancement in the onset of flowering has been observed, especially in 2000 and 2004 and it is anticipated that this trend will continue with the expected climatic projections. Flowering advancement exposes the olive fruits to olive-tree fly (*Bactocera oleae*) attack which can cause severe economic losses. This condition would necessitate more intensive use of chemical treatments.



Wintering stage | Vegetative development | Inflorescence emergence | Inflorescnce development | Corolla defferentiation | Flowering start

Full flowering | Petal fall | Fruit set | Fruit development I | Fruit development II

Figure 2: Reference phenological stages of olive tree as given by Collebran and Fabre (1975).

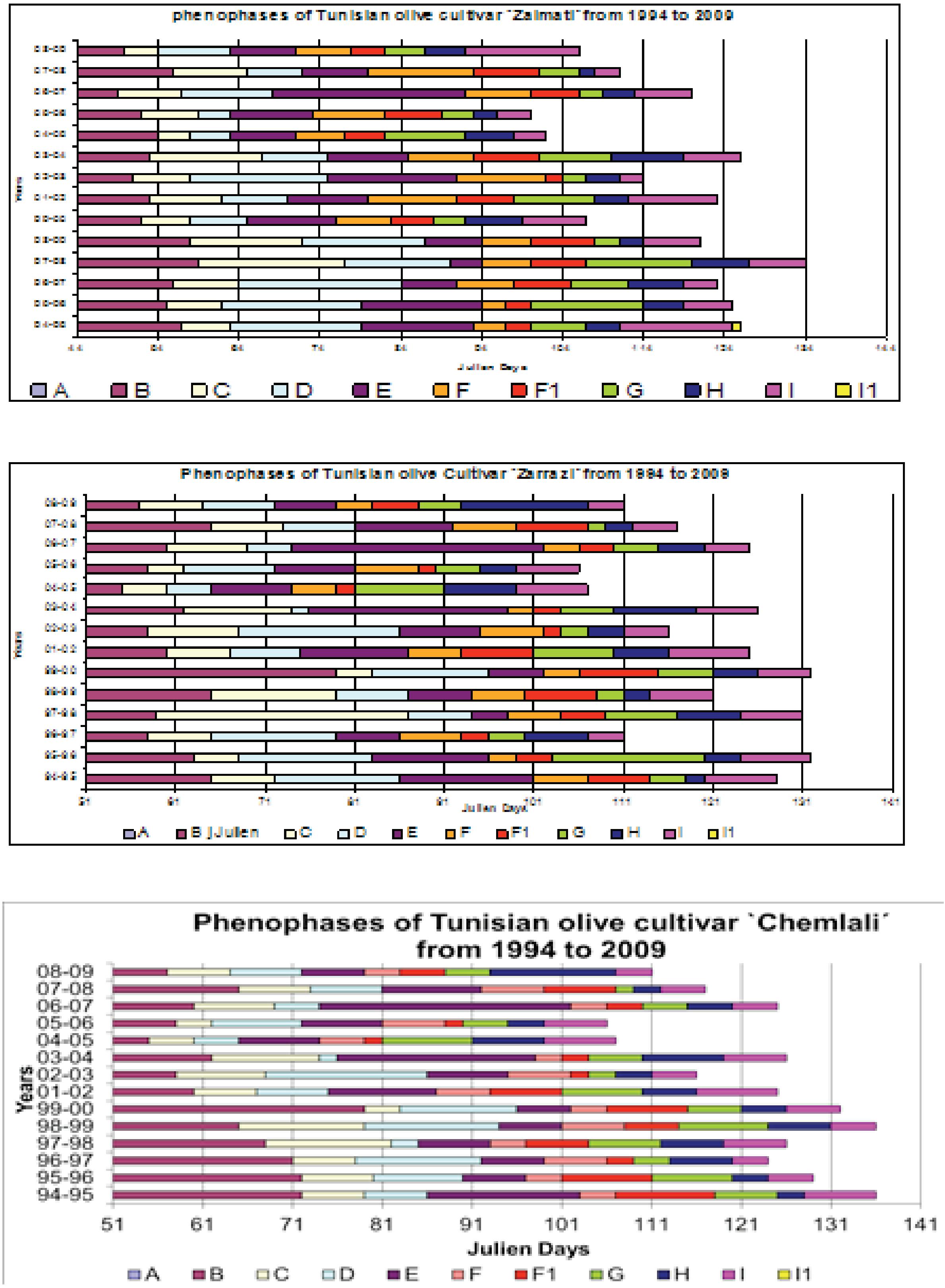


Figure 3: Changes in the phenophases of the three Tunisian olive cultivars over the period 1994 to 2009.

Introduction

The olive tree (*Olea europaea* L.) is one of the most extensive crops in the Mediterranean region. Fruits and oil are among the most important products for the economy of this area. Nearly 95% of the total area under olive crop of the world is concentrated in the Mediterranean Basin (South Europe and North Africa) where olive cultivation originated about 6000 years ago.

Tunisia's olive resources are estimated at over 65 million olive trees, grown on 1.68 million ha. Olive tree is widely spreading over the country from north to the south and is mainly cultivated under rainfed conditions. The main production regions are characterized by arid and semi arid climate with high evaporative demand, high solar radiation and an irregular and scarce precipitation (less than 200 mm year^{-1}). Moreover, cyclic severe drought is observed which has been amplified by limited water resources for irrigation. With projected climatic changes, drought will be more frequent. It is widely known that drought may be considered as one of the most serious environmental constraints in the arid and semi-arid areas of Tunisia. These regions are subjected to severe water scarcity conditions and high evaporative demand because of global warming. Olive phenolology is an indicator of global climatic change. Especially during spring months the rising spring temperatures during the past and current centuries have advanced the timing of leaf development and flowering in many cultivars of olive (Osborne *et al.* 2000).

Methodology

In the present work we study the impact of global warming on the olive tree in the south-east of Tunisia, where nowadays a certain doubt has started about the future of this crop. The study focuses on floral phenology observations during 18 years (1992-2009) on three Tunisian cultivars ('*Zalmati', 'Chemlali',* and *'Zarrazi'*).

Phenophase series observations were recorded on 20 trees for each cultivar (at Zarzis, south of Tunisia (33°36'N longitude; 11°02'E latitude; 9 m above the mean sea level (Figure 1). The reference phenological stages of olive tree are shown in Figure 2 (Collebran and Fabre 1975). The long term average nnual rainfall here is 180 mm; minimum temperature 4.7°C in Januray, and maximum temperature 35°C in August.

Figure 1: Site of the study in south-east Tunisia.

Results

Phenological development

The changes in the phenophases of the three cultivars over the period 1994 to 2009 are shown in Figure 3. It is clear that there is a general trend for various phenophases to the precocity over the studied period although there are some year to year variations in the onset of various stages (Figure 3). The duration of vegetative growth of cultivar Chemoli (Figure 4) shows a clear tendency for decrease over the period of this study. The duration of flowering has shown a clear trend for increase over the period of study (Figue 5). The start of the fruiting has shown a clear trend for advancement (Figure 6).

Temperature changes

The minimum average temperature of the two most cold months (December and January) showed a marked tendency to increase over the period of study (Figure 7). This is a reflection of global climate change. The trend in temperature has influenced the phenology of the olive trees and some varieties are more sensitive than others, as shown by the behaviou of cultivar Chemlali (Figures 4, 5 and 6).

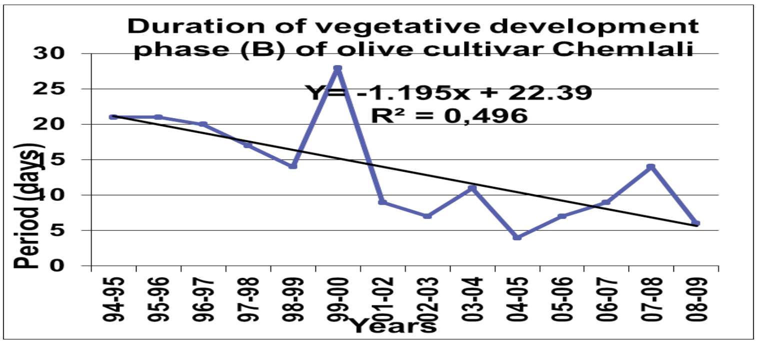


Figure 4: Change in the duration of vegetative growth of cultivar Chemlali over the studied period.

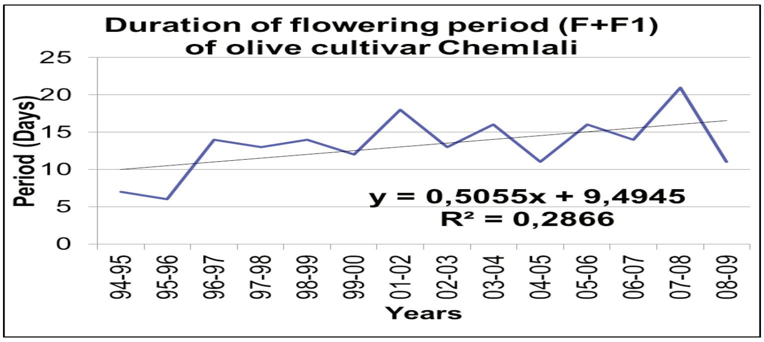


Figure 5: Spread of flowering period of cultivar Chemlali over the studied period.

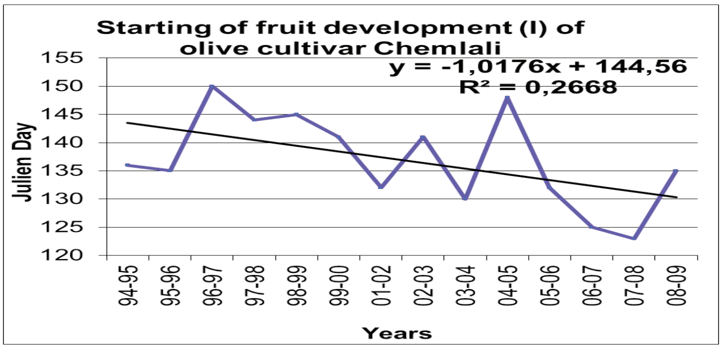


Figure 6: Precocity of fruit development phase of cultivar Chemlali over the studied period.

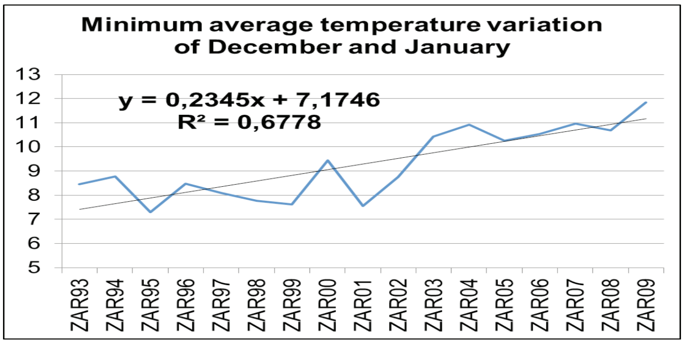


Figure 7: The minimum average temperature of the two most cold months (December and January) marked a growing tendency.

Figure 8: Olive fruit drop caused by olive fruit fly.

Discussion

South Tunisia has a climate characterized by hot, dry summers and mild, rainy winters. However, it is also characterized by a marked year-on-year variations in weather patterns and present a great spatial variability of this features. Also, the south Tunisia region has been identified as one of the regions likely to be most affected by future climate change. The trend for rise in temperature of the two coldest months is very clear (Figure 7). This has influenced the poheonolgical development of olive trees. Especially for the Cultivar Chemllali, starting from 2000, the frequency of the years with very early flowering has increased. The advancement in flowering over the period of study has been 25 days. From the year 2004, the years with late flowering have become rarer.

Advancement in flowering predisposes olive fruits to the attack by the olive-tree fly (*Bactocera oleae*). This fly attacks the fruit when it becomes about 6mm in size. With early flowering this phase of fruit development occurs well before the hottest period of June arrives which is known to kill the insect naturally. The fly can therefore escape the excessive heat and causes serious damage to the crop (Figure 8). The attack of the fly caused an economic loss of 30% in the year 2010. To protect the crop from the fly, the trees have to be treated heavily with insecticides which increases cost of production on one hand and causes environmental hazard on the other.

Conclusion

Climatic variability has increased during the last decades, and there is a clear trend for rise in the temperature of coldest months, which has caused advancement in the arrival of various phonological stages. The changes in phenological behavior of olive cultivars have made them more vulnerable to the olive fly, which is causing severe yield losses. Strategies will have to be developed to cope with this adverse impact of climate change.

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Vulnerability of Crop to climate change: A case study of elevated ozone and its impacts on leaf morphology in Thai soybean

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Abstract

The increasing tropospheric ozone level is one of the problems due to the global climate change. This problem has also affected worldwide agricultural for many decades. Therefore, investigating specific impacts of increased ozone on crop plants is an important area of research. This study aimed at investigating the response of Thai soybean (*Glycine max* (L.) Merill cv. 'Chiangmai 60') in terms of morphological and anatomical characters to elevated ozone levels. The crop was grown from January to April 2011 in top-opened chambers of Naresuan University crop field, Phitsanulok, Thailand. The experiment comprised of 3 treatments, CF (Charcoal filtered), NCF (Non-Charcoal filtered) and CF+O_3 (Charcoal filtered plus ozone), in order to create 3 ozone concentrations. Increasing ozone concentrations significantly reduced plant height and leaf areas index at the R3 stage. In addition, the elevated ozone also decreased the leaf pigments (chlorophyll *a* and chlorophyll *b*) as compared to control. The leaf color changed from green to reddish yellow and leaves were damaged. Mostly guard cells were damaged and the number of stomata closing increased.

Introduction

Greenhouse gases, such as NO_2, CO, CH_4 and volatile organic compounds (VOCs), are considered as the main factor causing climate change and global warming. In last few decades. Atmospheric ozone in troposphere layer is also one of the important factors in affecting the regional climate; changes in the last few decades may have played an important role in affecting the climate change and global warming phenomena (Akimoto *et al.* 2007).

Ozone is a major secondary air pollutant, produced by a complex series of photochemical reactions from primary precursor emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) and hydrocarbon groups. Recent studies have shown that NO_x is the main substance that causes ozone formation in urban areas; besides, high concentration of ozone is driven by high temperature and intensive light (Bergin *et al.* 2005; Stevenson *et al.* 2005 and Stathopoulou *et al.* 2008). In recent years, ozone concentrations have increased rapidly in developing countries, especially in Asia. For example, in the period 1982–2003, ozone concentrations in Beijing, China, increased from a daily maximum of about 40 ppb to about 125 ppb (Shao *et al.* 2006). Oltmans *et al.* (2006) found that in the 1980s-2000s, the concentration of ozone increased in Europe and Japan, especially during the months of March-June.

Tropospheric ozone is also of global interest because of its harmful effect on crops and human health (Lal *et al.* 2012). Effects of elevated ozone concentration include a decrease in plant growth and an alteration in plant metabolism that would ultimately reduce the crop yield. Furthermore, ozone sensitive plants frequently exhibit visible foliar injury, and also show reduction in nutritional quality. These effects may be due to effect of ozone in physiological processes of plants such as stomata functioning, photosynthesis, respiration, and translocation of photosynthesis.

Ozone affects the rate of opening of stomata and the chloroplast (Pleijei *et al.* 2004). It reacts with cell walls and membranes, causing membrane disruption and subsequent cell death with chlorotic flecking, necrosis and bronzing of foliage. Visual injury to crop plants caused by ozone can be used as a biological indicator to assess the impacts of air pollution (Coulston *et al.* 2002; Burkey *et al.* 2005; Heinz 2007; Nydick 2010) because of an increase in ozone.

Soybean is among the crop species most vulnerable to ozone damage. Using mathematical models, it is reported that in 1990 China, Japan and Korea, lost up to 23-27% yield of soybean under the impact of ozone (Wang and Mauzeral 2004). The study of Morgan *et al.* (2006) found that increasing the concentration of ozone in the average day by 13 ppb causer yield reduction in soybean by 20%. The study on impacts of ozone on the morphology of soybean leaves to serve as a base for developing biological indicator ofair pollution and climate changes is of great interest.

Materials and methods

The study was conducted at the crop research garden of the Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok, Thailand. It is situated at 16^0 44.003'N 100^0 11.812 'E and approximately 170 m above mean sea level. The duration of study was from January to April 2011.

The experiment was conducted with 3 different levels of ozone in Open-top chamber (OTC), (3 m long x 3 m wide x2 m tall).To get ozone concentration below the natural ambient level a charcoal - filtered (CF) was used. For natural ambient ozone level no charcoal filter (NCF) was used. To increase the ozone concentration above the natural level, a combination of charcoal-filter plus ozone ($CF+O_3$) from an Ozone generator of a capacity of 300 mg/hr was used. The experiment was conducted in a Randomized Complete Block design with 3 replications.

Soybean selected for the study was 'Chiang Mai 60' cultivar as it is widely cultivated in the lower parts of Northern Thailand. Seeds of soybean were planted in 3 rows with 50x20 cm spacing, irrigated every 7 days, and then covered with the Open-top chambers at the V2 stage of soybean growth (about age 22 days). Exposure to ozone was for 7 hrs/day (9:00 am – 04:00 pm).

Soybean plant height was measured at frequent intervals. Leaflet growth was analyzed continuously by measuring leaflet length (L) and width (W) of middle leaflets as this can be used as a proxy for leaf area measurements (Ainsworth *et al.* 2005). Leaf area index was calculated by the equation $LAI = LA/G$, where LA is leaflet area estimated from the relationship $LA = L\text{x}W\text{x}0.74$; and G is the land area covered by a plant.

The acetone extract of homogenized leaves was used to measure the pigment content with an absorbance spectrophotometer. The 663 nm wave length was used for chlorophyll *a*, 645 nm for chlorophyll *b*, and 470 nm for carotenoid pigments. Chlorophyll content was calculated according to Lichtenthaler and Wellburn (1983):

Chlorophyll *a* (mg/g fw) = 12.81* (A663) – 2.81* (A645)
Chlorophyll *b* (mg/g fw) = 20.13* (A645) – 5.03* (A663)
Carotenoids (mg/g fw) = (1000* A470 – (3.27*[chl *a*] – 104*[chl *b*]))/229

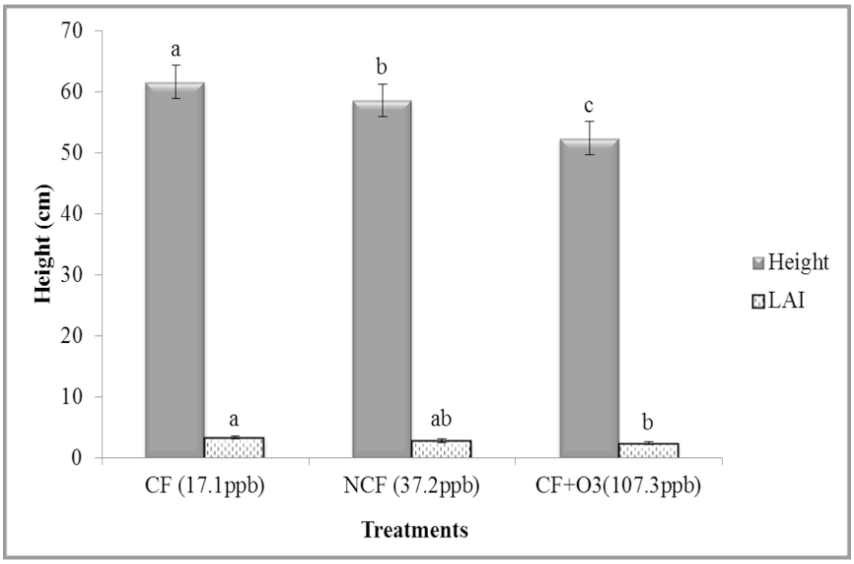

Figure 1: Soybean plant height and LAI as affected by different ozone treatments. Data represent the means ± SD, and bars with different letters (a-c) indicate significant differences at $p< 0.05$.

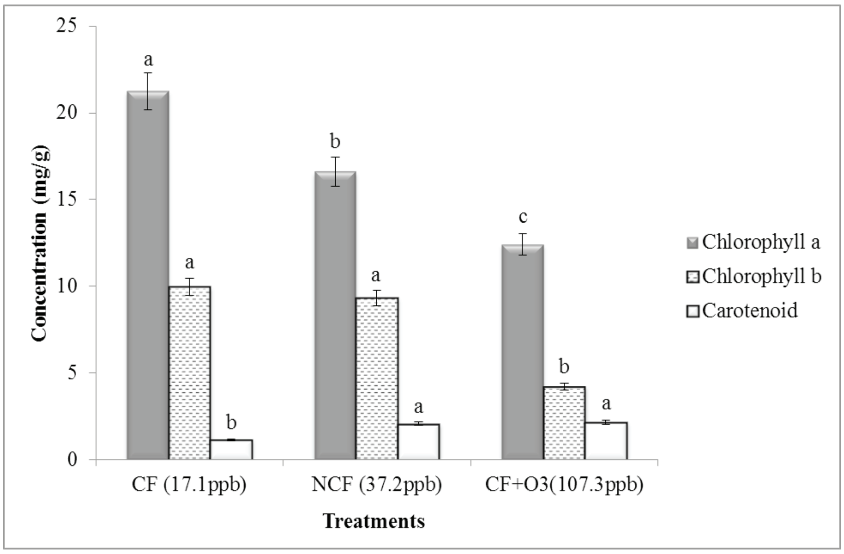

Figure 2: Soybean leaf pigment content as affected by different ozone treatments. Data represent the means ± SD, and bars with different letters (a-c) indicate significant differences at $p< 0.05$.

During the ozone exposure period, the visible injury index of leaves was scored regularly using the following six point scale (the percentage of injury in parentheses): 1 (0%), 2 (1-6%), 3 (7-25%), 4 (26-50%), 5 (51-75 %.) and 6 (> 75%) (Vollenweider and Goerg ٢٠٠٥). The change in color of leaves was studied following the exposure to ozone and classified in five categories in the order of increasing damage from ozone exposure: green, yellowish green, yellow, reddish yellow, and reddish brown.

Results were analyzed statistically with one-way analysis of variance. Duncan’s multiple range test was employed to analyze the differences between measured parameters ($p<0.05$).

Results and discussion

Ozone data were obtained from Photometric O_3 analyzer-model 400E (Ozone monitor) during the period March-April 2011. The average concentration of ozone was 17.1, 37.2 and 107.3 ppb, respectively, in CF (Charcoal filtered), NCF (Non-Charcoal filtered) and CF+O_3 (Charcoal filtered plus ozone) treatments

Impact of ozone on growth of soybean

Ozone affected the height of the stem, as measured from ground level to the top. In the CF, NCF and CF+O_3 treatments, the average height was 61.6, 58.5 and 52.4 cm, respectively. With ozone concentrations higher than natural there was an average decrease of 10.46% in height and 15.05% in the leaf area index (LAI) as compared with the control (Fig.1).

The results on the effect of elevated ozone concentration on LAI and height are consistent with those observed by other researchers. Calatayud (2003), studying the physiological mechanisms, showed that ozone diffusion through the stomata resulted in closure of stomata, reduction in the rate of gas exchange, especially the CO_2 in leaf mesophyll, and reduction in the efficiency of carboxylation. Borowiak and Wujeska (2012) found that of high concentration tropospheric ozone directly affected the height of tobacco and peanut plants. Zouzoulas *et al.* (2009) reported that at a level of 100 ppb ozone the LAI of cotton was significantly reduced.

Impact of ozone on pigment content

In the study, chlorophyll and carotenoid were measured at the R3 stage (Fig. 2). Significant reduction was found in both chlorophyll *a* and chlorophyll *b* by elevated ozone level. Ozone concentration of about 107.3 ppb (CF+O_3) caused 25.18% and 54.73% reduction in chlorophyll *a* and chlorophyll *b*, respectively as compared to control (NCF). However, a significant increase by 4.85% was found in carotenoid pigment 9.

Reduction in chlorophyll content of leaves following exposure of plants to ozone has been reported in many species. Saitanis *et al.* (2001) found that the increase in the concentration of ozone from 90 ppb to 135 ppb for 8 hrs /day for 20 days caused chlorophyll reduction in *Nicotiana tabacum* L., *Avena sativa* L., and *Hedera helix*. The effect was more strong on chlorophyll *a* than chlorophyll *b*. Moreover, there were necrotic and chlorotic symptoms on leaf surface and the aging of leaves was accelerated. This was associated with a decrease in photosynthesis. Ozone level increase caused reduction in the amount of chlorophyll in chloroplast of *Pistacia lentiscus* L. (Arminana *et al.* 2004). Ramaškevicienė *et al.* (2008) reported that high ozone levels under climate warming caused a reduction of 18-29% in pigment in the leaves of soybean and reduced their length and biomass.

Impact of ozone on leaf color and injury of soybean

Elevated ozone concentration changed the color and caused damage to the leaves. The leaves, under ozone level higher than the natural, changed their color from green to reddish yellow and 53.3% of them gave damage rating of 6. A lot of damage occurred to stomata; mostly guard cells were damaged (Fig. 3). The thickness of the palisades decreased by 3.8% with increased cell death.

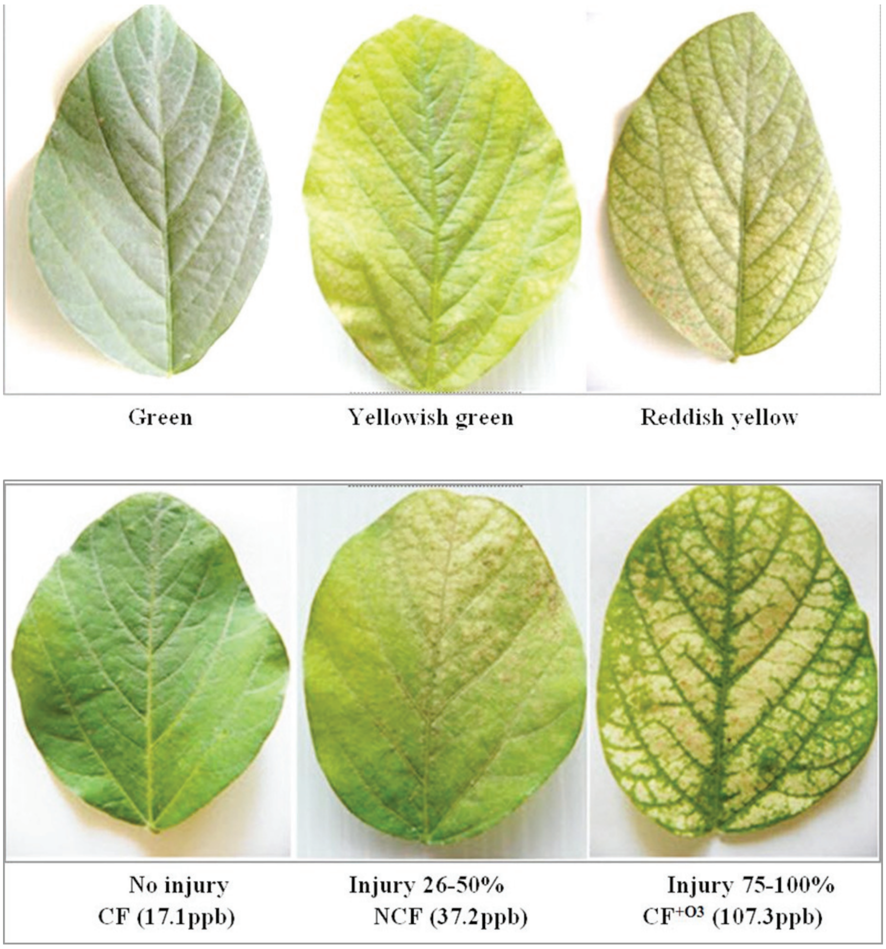

Figure 3: Soybean leaf color and injury as affected by different ozone treatments.

Ozone exposure stimulates an oxidative burst in leaves of sensitive plants, resulting in the generation and accumulation of hydrogen peroxide or superoxide anions in different species. Accumulation of these ROS precedes the induction of cell death, and both responses co-occur spatially in the periveinal regions of the leaves (Edwin *et al*. 2005). Amplification mechanisms that result in the production of excess ROS and hypersensitive cell death are suggested as major factors in ozone toxicity (Christian *et al.* 2002).

Paoletti *et al.* (2009) found that elevated ozone levels had an adverse impact on the radical structure of stomata in young leaves of the Manna ash (*Fraxinus ornus* L.), affecting gas exchange and reducing the absorption of carbon dioxide in the stomata. Ozone-induced closure of stomata caused a reduction of the (Reiling and Davison 2006). Dolan (2011) found that the composition of the tissues inside the leaf of coneflower (*Rudbeckia laciniata* var. *digitata*) is sensitive to ozone; there is a reduction of the cell wall of palisades mesophyll. The surface tissue had increased cell death and the pigment density was reduced.

Conclusion

The results of this study indicate that the increase in the concentration of ozone negatively affected various growth attributes that determine seed yield. The amount of chlorophyll *a*, chlorophyll *b* in the leaves decreased and leaf color changed from green to reddish yellow when the ozone concentration was 3 times higher than natural. There was a decrease in the thickness of the cells in the palisades. Affecting directly the photosynthesis, these impacts of elevated ozone levels would decrease the productivity and food quality of soybean. Therefore, the relevant departments of the government (Department of Agriculture and the Department of Pollution Control) should provide policy directives and planning to prevent ozone increase in agricultural areas. Finally, biological indicators of O_3 damage to crops should be published to inform farmers so that they may use the information to monitor their crop themselves.

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Air pollutants and waste mitigation with chicken-egg farm management in Northern Thailand under global warming situation

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Abstract

The increases of air temperature in Thailand due to global warming situation have strongly induced the emission of air pollutants and odor from general livestock farms including chicken-egg farms. This study focused on the chicken-egg farm management in Northern Thailand, where the waste discharge and NH_3 emission in housing leads to severe odor problem. In addition, high temperatures in open housing (non-evaporative system) induced an increasing in CO_2 and NH_3 concentration because the high temperatures caused increase in respiratory rate of chickens. The enhancement in CO_2 concentration was significantly higher in the higher temperature area of the housing than in the lower temperature areas. However, the results of NH_3 concentrations were not significant. In the house equipped with evaporative cooling system air temperatures were lower than in the open housing and within this system the CO_2 and NH_3 concentrations were lower than in the open housing. The survey results showed that most chicken-egg farm owners in Northern Thailand have been using the evaporative cooling system for air pollutants and waste mitigation instead open housing system. In conclusion, the evaporative cooling system could mitigate the problem of high CO_2 and NH_3 concentration and odor problem in chicken-egg farms associated with high temperatures.

Introduction

Global greenhouse gas emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Increasing emissions of concentrations of greenhouse gases (GHGs) due to human activities have led to a marked increase in atmospheric GHG concentrations (IPCC 2006). It is widely recognized that increases in the GHGs in the atmosphere will cause global warming (Christie *et al.* 2011). In addition, the Intergovernmental Panel on Climate Change (IPCC) has concluded that measured global temperature increases are very likely to be the result of these higher GHG concentrations (Franks and Hadingham 2011).

One of the most potent greenhouse gases is CO_2. It is emitted from various sources worldwide. A number of studies examined the major factors affecting the CO_2 emission in different countries and regions. General livestock farms are amongst the important sources of GHG emissions (Zervas and Tsiplakou 2011). Studies in Greece have shown that the livestock systems based on grazing and the mixed farming systems will be more affected by global warming than the industrialized systems (Zervas and Tsiplakou 2011).

Providing one-third of humanity's protein intake, the global livestock industry currently employs 1.3 billion people and accounts for 40% of agricultural GDP (Steinfeld et al. 2006). On the other hand, livestock activities are estimated to contribute, directly or indirectly, 18% of the total anthropogenic GHG emissions measured in CO2-eq., thus affecting the climate change and its associated adverse health consequences (Zervas and Tsiplakou 2011).

Direct emissions from livestock come from the respiratory process of all animals in the form of CO_2. Indirect sources are the animal wastes, which also cause environmental pollution. Poultry have the highest GHG emission: 1.85 kg CO_2 per kg BW (Zervas and Tsiplakou 2011). The chicken-egg farms in Northern Thailand are a cumulative source of wastes, dung and air pollutants owing to lack of efficient management. Indoor air pollutants at high concentrations in poultry houses can also potentially affect worker's health, animal welfare, productivity and environment (Qin-Ni *et al.* 2012). Efficient management could mitigate these problems. Evaporative cooling system (EVAP) has been developed for chicken egg farms in Thailand to reduce the problem, but there are no reports on the amount of CO_2 emission reduction and its association with air temperature level in the housing in contrast to open house poultry farms. The main objective of this study was to monitor the relationship between level of air temperature and CO_2 emission in chicken-egg farms with and without evaporative cooling in Northern Thailand.

Material and method

The study was conducted at Maefak sub-district, Sansai district, Chiang Mai, in Northern Thailand. Figure 1 shows the selected sampling area, where both open housing and evaporative cooling houses were located.

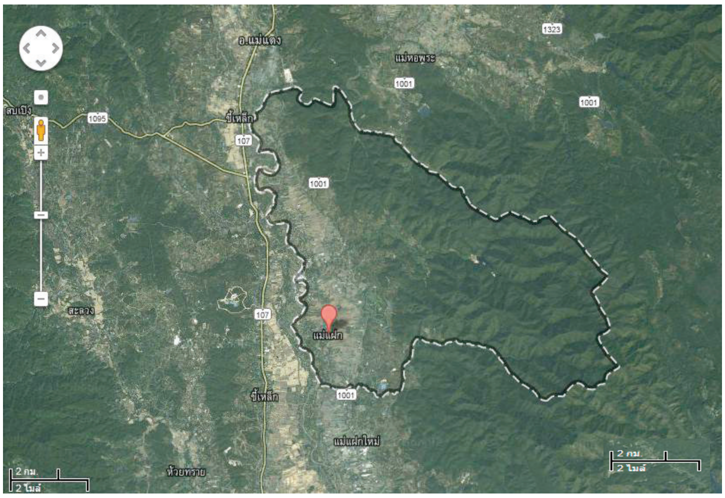

Figure 1: Map of the site where this research was conducted.

The methodology used in this study contained three main steps. First, a survey of scientific literature was done to identify the level of emission of CO_2 and NH_3 and the air temperature in the study areas. Second, chicken-egg farms were set into 2 sub groups - closed housing system (Evap: Evaporative Cooling System) and open housing system (Non-Evap: Non Evaporative Cooling System). Third, a field study was carried out in 2012 using these two types of farms as two treatments, and an additional treatment in which ozone level was elevated by an ozone generator (Belle Marketing Co.LTD, Thailand Model OZ-3020) (assign as CF-Ozone) . CO_2, NH_3, temperature and relative humidity were used as the parameters to indicate air quality in these treatments.

The levels of CO_2 and NH_3) were detected by CO_2 monitor (model testo 535) and multi-gas monitor (brand IBRID, model MX6), respectively. The O_3 level was determined by photometric O_3 analyzer (model 400 E). Temperature and relative humidity were measured by digital humidity/

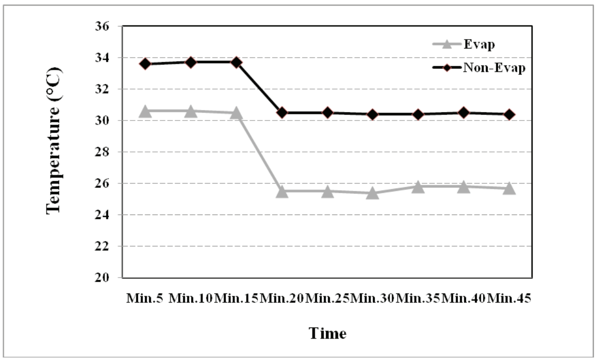

Figure 2: Temporal air temperature in two areas of chicken egg farm: Evap system farm and Non-Evap system farm

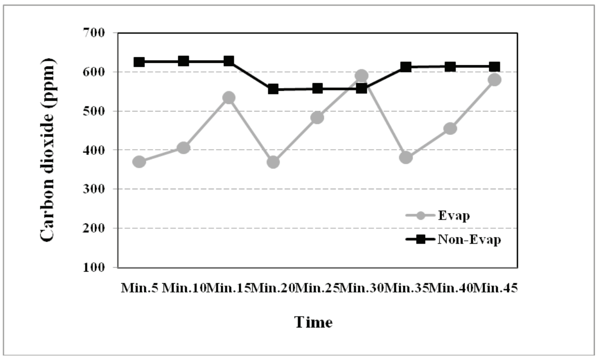

Figure 3: CO_2 concentrations (ppm) in two types of chicken- egg farms: Evap system farm and Non-Evap system farm.

temp meter (brand dig icon model.DM 750). The results were analyzed statistically with analysis of variance (ANOVA). Significant difference of results were reported at $p<0.05$ by DMRT.

Results and discussion

Temperature level

Results in Figure 2 show the temporal air temperature levels in two types of farms (Evap system and Non-Evap system). The average temperature in Evap system area and Non-Evap system area 27.27 °C and 31.52 °C, respectively clearly showing the lowering of the temperature by about 4 °C by evaporative cooling.

Carbon dioxide concentration

CO2, originating from animal respiration as well as from manure breakdown, is an important gas in confined animal buildings (Qin Ni et al. 2012). The levels of CO2 concentration in closed (Evap system) and open (Non-Evap system) housing systems are shown in Figure 3. The average concentration of CO2 in closed housing system (Evap system) was 135 ppm less than the CO2 levels in open housing system (Non-Evap). In addition, the highest concentration of CO2 reached 589 ppm (Min.30) in closed housing, while that in the open housing it could reach to

Table 1: Four parameters (Temperature Carbon dioxide, Ammonia, and Relative Humidity) in two types of farms: Evap system farm and Non-Evap system farm

Time (Minute)	Evap				Non-Evap			
	Temp (°C)	CO_2 (ppm)	NH_3 (ppm)	Humidity (%rH)	Temp (°C)	CO_2 (ppm)	NH_3 (ppm)	Humidity (%rH)
Min.5	30.6	371	3.0	60.1	33.6	626	6.0	52.2
Min.10	30.6	407	3.0	60.2	33.7	627	6.0	52.2
Min.15	30.5	534	3.0	60.2	33.7	627	6.0	52.2
Min.20	25.5	368	5.0	71.1	30.5	555	6.0	58.1
Min.25	25.5	483	5.0	71.0	30.5	557	6.0	58.0
Min.30	25.4	589	5.0	71.0	30.4	557	6.0	58.0
Min.35	25.8	380	4.0	61.2	30.4	612	6.0	53.2
Min.40	25.8	456	4.0	61.4	30.5	614	6.0	53.0
Min.45	25.7	580	4.0	61.4	30.4	614	7.0	53.0
Average	**27.27**	**463.11**	**4.0**	**64.18**	**31.52**	**598.78**	**6.1**	**54.43**

627 ppm (Min.10 and Min.15). However, this concentration did not exceed the standards of the Department of Livestock Development (2003) and Pollution Control Department (2011).

Ammonia concentration

The IPCC Guidelines for national greenhouse gas inventories specify ammonia gas (NH_3) is one important greenhouse gas (IPCC 2006). Livestock production is the most important source of ammonia (NH_3) in the atmosphere (Sommer *et al.* 2008). Ammonia is one of the main gases emitted from laying chicken houses (Lin *et al.* 2011). In this study, the data in Figure 4 show the average NH_3 concentration in the close housing system (4.0 ppm) was less than the average level (6.1 ppm) in the open housing system. However, the concentrations did not exceed the standards of the Department of Livestock Development (2003) and TLV-TWA Threshold limit value, average exposure on the basis of a 8h/day, 40h/week work schedule.

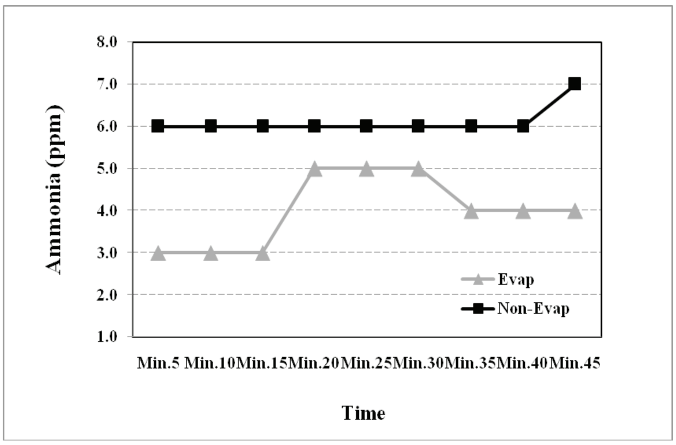

Figure 4: NH_3 concentrations (ppm) in two areas of chicken egg farm: Evap system farm and Non-Evap system farm.

Table 1 shows the comparison for temperature, CO_2 and NH_3 concentration, and Relative Humidity between closed housing system (Evap) and open housing system (Non-Evap). The average temperature in closed housing system is less than open housing system. So was the case with average CO_2 and NH_3 concentrations. Relative humidity in closed housing system was higher than in the open housing system.

Animal farm activities emit considerable concentrations of green house gases. Direct emissions come from the respiratory process of all animals in the form of CO_2 (Qin Ni *et al.* 2012). Animal manure also emits gases such as methane (CH_4), nitrous oxides (N_2O), carbon dioxide (CO_2), depending on the way it is produced (solid and liquid) and managed (collection, storage, spreading) (Steinfeld *et al.* 2006). Our results demonstrated the similar results as mentioned above. We found that high level of air temperature in open housing system (Non-Evap) area induced significant increase in CO_2 concentration. Whereas, CO_2 concentrations were quite stable in the Evaporative Cooling System (Evap) area due to the controlled air temperature (lower than air temperature in Non-Evap area). These results indicate that keeping air temperature lower in the Evap system than the ambient level caused reduction in the CO_2 level.

Conclusion

The CO_2 emission in the poultry farm is positively related to temperature in the housing. The open housing system (Non-Evap) resulted in increase in the level of CO_2 emissions than closed housing system (Evap) because of temperature differences. The farmer in Northern Thailand should therefore change from open to closed housing system for controlling and decreasing temperature within housing, and decreasing concentration of CO_2 emission to the surrounding area.

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Theme 4
Sustainable use of water resources in dry areas

Modeling evapotranspiration of applied water in Egypt Delta

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Abstract

Agriculture in Egypt is receiving the biggest share of developed water supply, amounting to nearly 85% of the available water resources. The policy of Egypt is to increase the food production through expansion of the irrigated areas. As about 97% of Egypt's water comes from outside Egypt, there is a need for serious action programs to increase water use efficiency. This research was conducted during years 2007-2009 at Sharkia (east Delta) and Kafr El-Shiekh (north Delta), which are typical of the Nile Delta region. The overall objectives were to help water policy planners to develop appropriate methodologies to determine crop coefficients and evapotranspiration rates for irrigated agriculture. The emphasis was on the introduction of SIMETAW model as a new tool for better water management. The SIMETAW model was calibrated using recent 10-year weather data sets at two sites in the Nile Delta. Its potential was then examined as a tool to evaluate the crop coefficients for wheat and maize. After calibration , it showed high accuracy in long-term simulation of daily weather parameters. It was efficient in projecting the Kc values for field crops cultivated under different irrigation strategies. It estimated *ETo* with acceptable accuracy from daily weather data using the daily standardized reference evapotranspiration equation and provided water balance estimates that assist in the evaluation of irrigation strategy for improved irrigation efficiency.

Introduction

Water scarcity is a serious current problem in Egypt. Yearly, many thousands hectares of land are reclaimed and added to the irrigated area in Egypt. Consequently, water limitations are rapidly increasing. Mismanagement of agricultural water resources, e.g., over-irrigation and the use of low quality water, are causing rapid land degradation due to salinity, alkalinity, and waterlogging problems. Opportunities for the significant capture of new water are limited. Most river systems suitable for large-scale irrigation are already developed, and most groundwater resources are tapped or over-exploited. The future of the irrigated agriculture mainly depends on agricultural water saving at both farm and basin levels. Technical and political attempts to conserve irrigation water are a top priority to mitigate the looming water scarcity.

One of the biggest deficiencies in water use planning is a lack of information on crop coefficients and crop water use. Although considerable information does exist, much of the literature is out-of-date because of changes in crops, management, and irrigation systems. In addition, the equation for *ETo* has changed since most of the crop coefficient values were developed for traditional irrigation practices. For example, current orchards that are irrigated twice per week by micro-sprinklers are likely to have different *ETc* than orchards that were surface irrigated every second week 30 years ago.

Application programs for water demand planning (i.e., SIMETAW and CUP Plus) are available to help determine seasonal crop coefficient (Kc) curves, standardized reference evapotranspiration (*ETo*) for short canopies (ASCE-EWRI 2005), crop evapotranspiration (*ETc*), and ET of applied water (*ETaw*) i.e. the net amount of irrigation water needed to produce a crop (Snyder *et al.* 2004). *ETo* is a virtual evapotranspiration rate that is estimated using a modified Penman-Monteith equation with fixed canopy resistance and aerodynamic resistance equal to an inverse function of the wind speed. Improvements to these application programs are possible if the information on Kc values and growth data are updated to better match current conditions. In addition, with the climate change, it is likely that the *ETc* of various crops will change relative to *ETo* and this will lead to changes in crop coefficients. It is critically important that the methodology be in-place for water policy maker to update Kc values as the climate changes.

SIMETAW is a weather generator application program developed by the California Department of Water Resources and the University of California to simulate many years of daily weather data from monthly climatic records to estimate *ETo* and with the simulated data and *ETc* using Kc estimates. In addition, simulated daily rainfall, soil water holding characteristics, effective rooting depths, and *ETc* are used to determine effective rainfall and to generate hypothetical irrigation schedules to determine seasonal and annual ET of applied water. SIMETAW is a user-friendly program that (i) calculates reference evapotranspiration (*ETo*) from simulated weather data, (ii) determines crop coefficients for a wide range of agricultural crops, (iii) accounts for many factors affecting crop coefficient (*Kc*) values that are generally ignored in other programs, (iv) generates a hypothetical irrigation schedule for each of the simulated years of data, (v) estimates effective rainfall (*Re*) and irrigation water requirement (*ETaw*), and (vi) calculates the mean *ETaw* over a specified number of years. When *ETaw* is divided by the irrigation efficiency, the result is a site-specific total irrigation requirement to produce a crop.

The SIMETAW model greatly improves our ability to rapidly and accurately determine *ETaw* at locations with weather stations, and the simulation part of the program helps to fill in missing data both spatially and temporally. It also provides the opportunity to investigate possible effects of climate change (e.g., changes in temperature, humidity, CO_2, and rainfall pattern) on water demand by agriculture irrigation (Snyder *et al.* 2004).

SIMETAW was modified and used to determine *ETaw* of the Sacramento-San Joaquin River Delta in California. More recently, projects were conducted to estimate *ETaw* for the Central Valley of California followed by a more extensive project to determine *ETaw* statewide. Since there are similar problems in the Nile Delta region of Egypt, we proposed a pilot study to collect crop and soil data and to apply the SIMETAW program to determine *ETaw* for the Nile Delta in Egypt.

The use of SIMETAW for water resources planning is expanding rapidly around the world. The SIMETAW model has been presented to the Climate Group and the Water Management Groups at the United Nations – Food and Agriculture Organization, and the possibility to change their climate data to allow them to use SIMETAW worldwide. Also the Peoples Republic of China has approached developing a cooperative project involving SIMETAW, to help them with water resources management.

This research was conducted to achieve the following objectives:

1. Improve our knowledge and tools by updating our methods to determine *ETc* and to better inform irrigators and water policy makers.
2. Upgrade and increase confidence in the Kc values.
3. Improve on-farm irrigation management.
4. Provide water demand estimates for regional water resources planning.

Wheat and maize, the two important strategic food crops, were used; wheat as an important winter crop and maize as an important summer crop.

Methodology

Sites characterization

This study was conducted at two sites in the Nile Delta (Figure 1): Zankloun, and Sakha during 2007-2009. The sites are typical of the Nile Delta (old lands) in such attributes as: the clay content of soil; Nile surface water for irrigation; intensive cropping pattern (2-3 crops a year) comprised of summer (maize, rice, cotton) and winter (berseem, wheat, faba been, sugar beet) crops; mainly surface irrigation system; increasing numbers of traditional and improved irrigation systems; extensive drainage systems; and land fragmentation (holdings less than 1 hectare represent more than 80% of the total holdings).

Figure 1: Map showing the study sites

Soil samples from both sites were analyzed to determine the soil physical and chemical properties. The average values of soil properties were measured down to 60 cm (Tables 1 and 2). Climate data including solar radiation (*Rs*), maximum and minimum air temperature (*Tmax* and *Tmin*), wind speed at 2 m above ground surface (U_2), dew point temperature (*Tdew*), precipitation (*Pcp*), and the number of rainy days (*NRD*) are presented in Tables 3 and 4.

Table 1: Soil physical and chemical properties of Zanklon site

Depth (cm)	Sand %	Silt %	Clay %	Bulk density g.cm-3	Field Capacity %	Wilting point %	Available water %	E.C dS.m-1	pH
0-15	25.80	28.90	43.51	1.25	43.51	23.55	19.96	1.40	8.10
15-30	25.12	30.10	42.50	1.27	40.50	21.06	19.44	1.22	8.00
30-45	26.90	31.50	40.50	1.35	37.12	17.59	19.53	1.25	8.01
45-60	27.78	31.50	39.12	1.41	36.25	16.64	19.61	1.05	8.01

Table 2: Soil physical and chemical properties of Sakha site

Depth (cm)	Sand %	Silt %	Clay %	Bulk density g.cm-3	Field Capacity %	Wilting point %	Available water %	E.C dS.m-1	pH
0-20	17.5	30.0	52.5	1.53	45.0	12.23	32.77	1.98	8.0
20-40	18.0	31.0	51.0	1.65	37.0	10.05	26.95	2.00	8.1
40-60	18.7	31.5	49.8	1.72	35.0	9.51	25.49	2.25	8.1

Table 3: Monthly climate data of Zanklon site

Month	Rs	Tmax	Tmin	U2	Tdew	Pcp	NRD
	MJ $m^{-2}d^{-1}$	^oC	^oC	m s^{-1}	^oC	mm	#
Jan.	14.8	19.1	5.6	1.0	7.56	16.0	6
Feb.	17.9	19.8	5.8	1.1	7.34	19.2	4
Mar.	21.5	22.8	7.2	1.3	8.46	5.1	2
April	24.0	27.5	10.9	1.5	11.63	0.0	0
May	27.7	32.0	14.6	1.7	14.07	0.0	0
June	29.1	34.2	18.6	1.8	17.47	0.0	0
July	28.5	34.5	21.0	1.3	20.98	0.0	0
Aug.	27.3	34.1	20.8	1.2	21.71	0.0	0
Sept.	24.1	33.1	18.8	1.2	19.06	0.0	0
Oct.	19.2	30.7	16.4	1.2	15.79	1.5	1
Nov.	15.7	25.1	11.9	0.9	11.95	6.5	3
Dec.	14.0	20.7	7.7	0.8	8.88	13.1	4

Table 4: Monthly climate data of Sakha site

Month	Rs	Tmax	Tmin	U2	Tdew	Pcp	NRD
	MJ $m^{-2}d^{-1}$	^{o}C	^{o}C	m s^{-1}	^{o}C	mm	#
.Jan	13.9	19.2	5.5	1.4	7.07	22.5	6
.Feb	17.2	19.8	5.6	1.4	7.41	24.2	4
.Mar	21.1	23.5	7.7	1.3	9.02	5.2	2
April	25.0	26.5	9.2	1.5	10.29	2.7	1
May	29.0	29.9	13.3	1.9	13.04	0.0	0
June	30.6	32.1	16.9	2.0	17.07	0.0	0
July	29.5	33.6	18.6	1.3	20.12	0.0	0
.Aug	28.0	33.4	19.9	1.2	20.98	0.0	0
.Sept	23.6	32.1	16.5	1.2	17.82	0.0	0
.Oct	18.9	29.8	14.1	1.3	15.30	2.8	1
.Nov	15.8	25.1	10.5	1.3	11.57	10.3	2
.Dec	12.8	21.0	6.0	1.2	9.00	17.5	3

Field experiments

Wheat experiments

At the Zanklon, wheat was sown on November 20, 21, and 18 and harvested on May 9, 8, and 11 in the 2007-08, 2008-09 and 2009-10 growing seasons, respectively. At the Sakha, sowing was on November 15, 15, and 18 and harvesting on May 15, 15, and 17, respectively. Recommended agricultural practices were applied. The experimental unit was 300 m^2 (20 15 × cm) that consisted of 160 rows of 15 m length that were spaced 15 cm apart with a border of 1.5 m between plots. The same irrigation treatment was applied at both sites. The amount of water applied at each event was determined as the amount needed to increase the soil moisture content (up to 60 cm depth) to field capacity.

Maize experiments

These were conducted during the 2007, 2008 and 2009 growing seasons at Zankalon Research Station. Seeds of 'T.W.C 310' cultivar were planted on 1 June 2007, 5 June 2008 and 2 June 2009 in rows 0.80 m apart on ridges with one plant/hill and 0.22 m between plants. All agricultural practices were similar to those used by local growers. Harvest dates were 5, 8, and 7 October in the three seasons respectively. The plots were approximately 15 m long, the furrows were about 0.20 m deep, and the ends of the furrows were blocked to prevent runoff from the field. The amount of water applied at each event was determined on the basis of raising the soil moisture content (up to 60 cm depth) to field capacity.

Applied water

The irrigation water used for the experiments had typical water qualities for the region with EC of 0.34 dS/m at Zanklon and 0.60 dS/m at Sakha. Applied water (*AW*) was measured using a calibrated flow meter with reading resolution of 5 decimals of m^3. Irrigation water was transferred to each plot through 0.20 m diameter polyethylene pipes, and the applications were controlled using a valve at the front of each plot. All plots received the same irrigation events including that at sowing. The irrigation was so managed to avoid any water puddles on the surface for more than 10 hours to reduce the evaporation and deep percolation losses.

Actual evapotranspiration

The actual evapotranspiration (*ETa)* was measured using a weighing lysimeter. The lysimeter dimensions were 2 m width, 4 m length, and 2 m depth, and it had a drainage system and digital and manual balance. The lysimeter was installed at the site of the experiments and it was surrounded by 200 m f*etc*h. The lysimeter was calibrated by gravimetric soil sampling at 15 cm depth increments in Zanklon and 20 cm depth increments in Sakha, down to 60 cm. Data were collected at sowing and before and two days after each irrigation as well as at harvest time to determine the *ETc* of wheat and maize crops according to Israelsen and Hansen (1962).

Weather data manipulation

The collected data were checked, scanned, and filtered to remove error and prevent the misleading analysis and data noise. The data were arranged into a specific format and then entered into a spreadsheet where they were prepared for use in SIMETAW to process the collected data.

Simulation accuracy assessment

The monthly means and totals of 10 years of daily measured weather data (1999-2008) of Zahnklon and Sakha were used in the model to simulate average daily weather data. The data consisted of *Rs, Tmax*, *Tmin*, U_2, *Tdew*, and Pcp. The SIMETAW simulations of daily weather data from monthly means were compared with the observed daily data to test the simulation accuracy.

Verification of the simulated *ETo* and *ETc*

For verification of the SIMETAW model, the *ETo* from simulated daily weather data was compared to 10-years of observed *ETo* (1999-2008) at Zanklon and Sakha using the modified Penman-Monteith equation. The potential accuracy of simulated *ETc* from the model was also evaluated by comparing it with observed *ET* of the two crops.

Crop coefficient (K_C) evaluation

The accuracy of the K_C values from SIMETAW was evaluated for wheat and faba bean as winter crops and maize as a summer crop. The wheat simulations were done for six growing seasons (between years 2003-2010), faba bean simulations were done for two seasons (between years 2004-2006), and maize simulations were done for three seasons (between years 2007-2009).

Methodology approach

Entering crop and soil information

Crop and soil information were input into a data file using a comma delimited format so the data were readable by MS Excel. The input data included the crop name, planting and harvesting dates, initial growth, irrigation frequency, pre-irrigation information, immaturity factors, presence of cover crops, soil water holding characteristics, maximum soil and rooting depths, *ETc*. Each row of data in the file contains a unique combination of the crop, soil and irrigation information.

Calculating the yield threshold depletion

Crop rooting depth, maximum soil depth, and soil water holding capacity are used to calculate the yield threshold depletion (*YTD*), which is used to make a crop and soil specific irrigation schedule. To simplify graphing, the water holding content at field capacity is estimated as twice the available water holding content. The *YTD* is calculated as the product of the crop-specific allowable depletion and the *PAW*.

Entering climate data

Either daily or monthly climate data are used to determine *ETo*. If monthly data are used, SIMETAW generates the daily weather data. Daily data files include precipitation and the monthly files have the monthly total precipitation and the number of days per month having significant precipitation which is defined as two times the daily *ETo* rate. When the daily data are generated from monthly climate data, the program forces a negative correlation between rainfall amount and *ETo* rate within each month assuming that rainfall is inversely related to *ETo*.

Weather simulation

Weather simulation models are often used in conjunction with other models to evaluate possible crop responses to environmental conditions. One important response is *ETc*, which is commonly estimated by multiplying *ETo* by a crop coefficient. In SIMETAW, only daily weather data are used to estimate *ETo*. Then *ETc* is estimated by multiplying *ETo* by an appropriate crop coefficient (K_C) value for that day of the season. Daily precipitation data are then used with calculated *ETc* to determine effective rainfall and *ETaw*. In the SIMETAW model, rainfall is generated using a gamma distribution function and Markov chain approach, whereas wind speed uses only a gamma distribution. Temperature, solar radiation, and humidity data use a Fourier series distribution. SIMETAW simplifies the parameter estimation procedure of Richardson and Wright (1984), requiring only monthly means as inputs.

Reference evapotranspiration calculation

Standardized reference evapotranspiration (*ETo*), for short canopies, is estimated from daily weather data using a modified version of the Penman-Monteith equation (Allen *et al.* 1998; Itenfisu *et al.* 2000; Walter *et al.* 2000; ASCE-EWRI 2005).

Crop coefficients

While *ETo* is a measure of the 'evaporative demand' of the atmosphere, *Kc* values account for the difference between the crop evapotranspiration *ETc* and *ETo*. The main factors affecting the difference are (1) light absorption by the canopy, (2) canopy roughness, which affects turbulence, (3) crop physiology, (4) leaf age, and (5) surface wetness. Because evapotranspiration is the sum of evaporation (*E*) from soil and plant surfaces and transpiration (*T*), it is often best to consider the two components separately. When not limited by water availability, both transpiration and evaporation are limited by the availability of energy to vaporize water. During early growth of crops, *ETc* is dominated by soil evaporation and the rate depends on whether or not the soil surface is wet. If a nearly bare-soil surface is wet, the *ETc* rate varies from slightly higher than *ETo* for low evaporative demand to about 80% of *ETo* under high evaporation conditions. As a canopy develops, interception of radiation by the foliage increases and transpiration rather than soil evaporation dominates *ETc*. Field and row crop K_C values generally increase until the canopy ground cover reaches about 75%. The ground cover percentage associated with the peak K_c is slightly lower for tree and vine crops because the taller plants intercept more solar radiation at the same ground cover.

ETaw calculations

Crop specific K_C values are determined from *ETo and* crop information that is stored separately in rows of a comma-delimited 'SAnnn.csv' file that is created as an input file by using the SIMETAW program. During the off-season, crop coefficient values are estimated from bare soil evaporation following the procedures of Ventura *et al.* (2006).

For effective rainfall calculations, SIMETAW assumes that all water additions to the soil come from rainfall and losses are only due to deep percolation. Because the water balance is calculated each day, rainfall, runoff and surface water running onto a cropped field are ignored. During the off-season, the maximum depletion allowed is 50% of the *PAW* in the upper 30 cm of soil. It is assumed that soil evaporation is minimal once 50% of the available water is removed. If the soil water depletion (*SWD*) is less than this value, the *ETc* is added to the previous day's *SWD* to estimate the current *SWD*. Once the *SWD* reaches the maximum depletion, it remains at the maximum depletion unless rainfall decreases the depletion. If rainfall occurs, the *SWD* depletion is decreased by the rainfall amount but never less than zero. If the *SWD* at the end of a cropping season starts at some value greater than the maximum soil water depletion, the *SWD* is allowed to decrease with rainfall additions but it is not allowed to increase with *ETc*.

Results and discussions

Weather data integrity and quality

The accuracy of determining *ETo* from weather data is based on the integrity and the quality of the original weather data sets. Therefore, assessments of weather data integrity and quality need to be conducted before data are utilized in *ETo* equations. Determining the quality of solar radiation data could be good indicator for the quality of the weather data sets, and it could be evaluated for a particular weather location by plotting hourly or daily average readings of solar radiation (*Rs*) against computed short wave radiation that is expected to occur under clear sky conditions (*Rso*). Under clear sky condition, the value of *Rs*/*Rso* is unity. Figures 2 and 3 show the values of *Rs*/*Rso* of the ten years of daily measured weather data (1999-2008), which represent the general trend of the study locations. The values of *Rs*/*Rso* ratio are close to 1.0 which implies that clear sky is common even during winter season.

Simulation accuracy of SIMETAW

The weather data (*Rs*, *Tmax*, *Tmin*, *Tdew*, U_2 and *Pcp*) simulated from SIMETAW were compared with the data from actual observations locations. The regression and correlation between the simulated and actual records for Znaklon site are listed in Table 5. Highly significant positive correlation was detected between actual records and estimated values from SIMETAW with high R^2 values. It can therefore be concluded that SIMETAW model could be used accurately and efficiently for filling the data gaps in the Nile Delta. Regarding Sakha site, the same trend as for Zanklon site was observed, however the correlation between the simulated and the observed data of the aforementioned parameters was stronger in Zankalon than Sakha (Table 6).

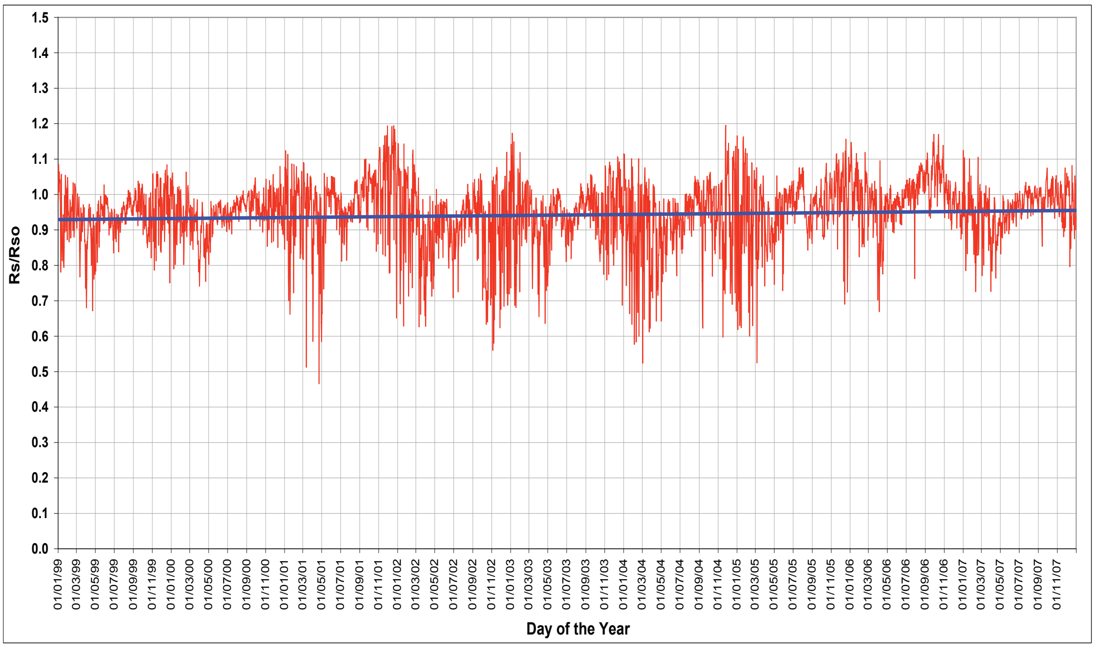

Figure 2: A plot of *Rs*/*Rso* ratio as an indicator for data reliability at the Zankalon site.

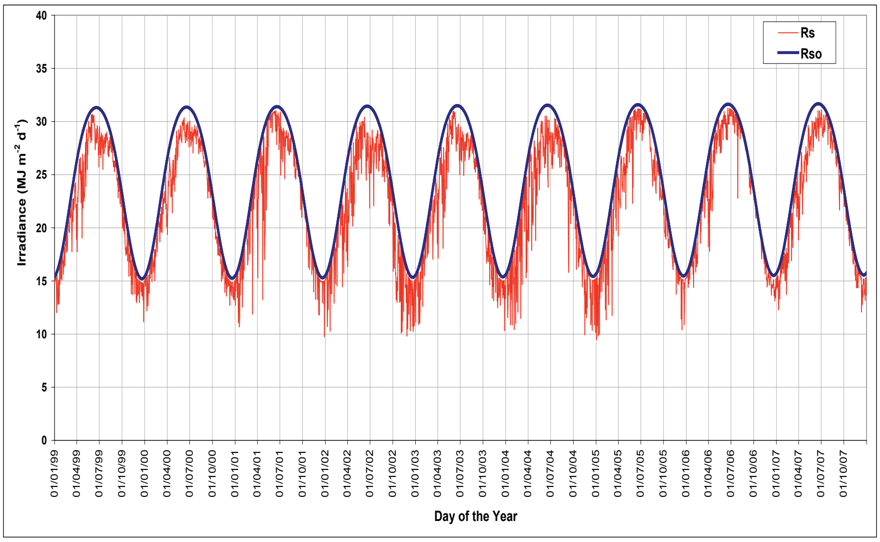

Figure 3: A plot of *Rs* and *Rso* versus time as an indicator for data reliability at the investigated area.

Table 5: Regression and correlation between the simulated data from SIMETAW and observed data at Znaklon

Dependent variables (recorded) y	Independent variable (simulated) x	Regression equations	Determination coefficient (R^2)
Rs ($MJ.m^{-2}.d^{-1}$)	*Rs* ($MJ.m^{-2}.d^{-1}$)	$y = 0.9227x + 1.5438$	*0.925***
Tmax (°C)	*Tmax* (°C)	$y = 0.9723x + 0.7655$	*0.952***
Tmin (°C)	*Tmin* (°C)	$y = 0.9858x + 0.1909$	*0.967***
Tdew (°C)	*Tdew* (°C)	$y = 0.9866x + 0.2226$	*0.956***

Table 6: Regression and correlation between the simulated data from SIMETAW and the actual observations in Sakha

Dependent variables (recorded) y	Independent variable (simulated) x	Regression equations	Determination coefficient (R^2)
Rs ($MJ.m^{-2}.d^{-1}$)	*Rs* ($MJ.m^{-2}.d^{-1}$)	y = 0.9307x + 1.7301	*0.890***
Tmax (°C)	*Tmax* (°C)	y = 0.9327x + 1.8469	*0.866***
Tmin (°C)	*Tmin* (°C)	y = 0.9685x + 0.3037	*0.927***
Tdew (°C)	*Tdew* (°C)	y = 0.9733x + 0.3534	*0.910***

There was also a good agreement between observed and simulated values of wind speed. The linear regression equation was $y = 0.977x + 0.0302$ and $R^2 = 0.650$ for Zanklon site and $y = 1.0307x - 0.0366$ and $R^2 = 0.657$ respectively for Sakha.

SIMETAW simulation, however, worked poorly for precipitation in the two locations (Figure 4 and 5) where there was no correlation detected between actual records and simulated values. The regression equations and determination coefficients (R^2) are $y = 1.391x + 0.1252, R^2 = 0.007$ and $y = 0.4027x + 0.1307, R^2 = 0.168$ for Zanklon and Sakha, respectively. This non-significant correlation may be attributed to the very low precipitation rate and sparse rainfall events. It is recommended that SIMETAW model could be modified for the rainfall simulation to better fit the Nile Delta conditions; however, the precipitation rates are so small, that effects on the water balance are small.

From the obtained results it could be concluded that SIMETAW model could be used for determining *ETo* for the studied region, whereas the model can accurately estimate daily data from monthly data and calculate *ETo* from daily weather data using a modified version of the Penman-Monteith equation (Allen *et al.* 1998). Moreover, if only temperature data are available, then SIMETAW calculates daily *ETo* using the Hargreaves-Samani equation.

Verification of the simulated reference evapotranspiration (*ETo*)

Figures 6 and 7 show the correlation between the daily mean *ETo* estimates from SIMETAW and the actual observations as an average of 1999-2008. A very high significant agreement exists between actual measurements-based calculations of *ETo* and those of the SIMETAW model. (The regression equation is $y = 0.9808x - 0.0453$ and the determination coefficient is $R^2 = 0.969$). The same trend was observed for Sakha site (the regression equation was $y = 0.9466x -$.(0.1688 and the determination coefficient was $R^2 = 0.928$

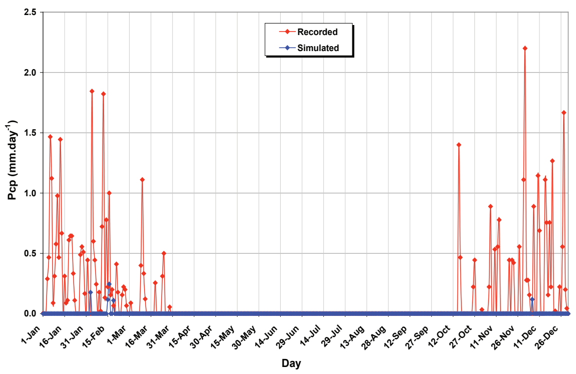

Figure 4: Comparison of measured and simulated mean daily rainfall at Zanklon.

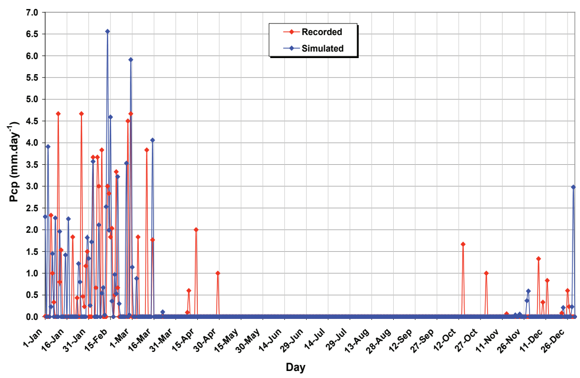

Figure 5: Comparison of measured and simulated mean daily rainfall at Sakha.

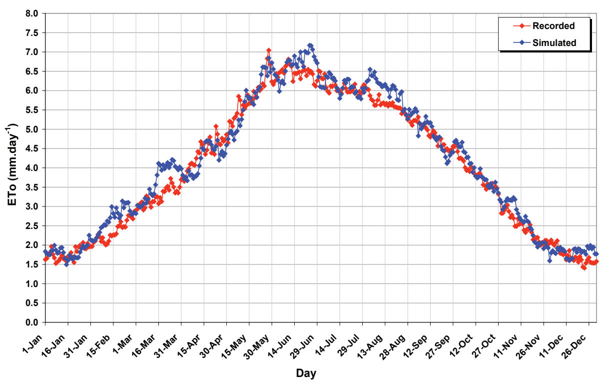

Figure 6: Mean daily simulated and observed *ETo* at Zanklon, over the years 1999 through 2008.

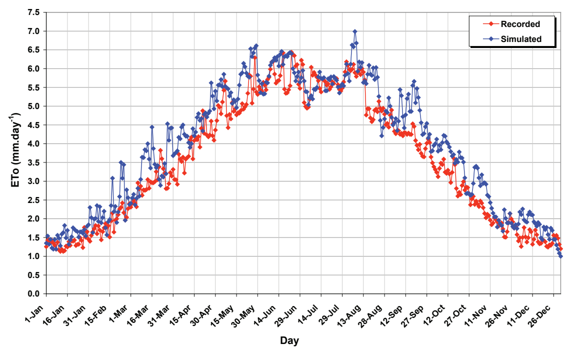

Figure 7: Mean daily simulated and observed *ETo* at Sakha, over the years 1999 through 2008.

Verification of the simulated crop evapotranspiration (*ETc*)

Use of SIMETAW for determining *ETc* was evaluated by determining the correlation between the simulated *ETc* values and the values observed using the lysimeter at Zanklon and soil water sampling at Sakha. This evaluation was done for maize and wheat. Figures 8 and 9 show a high agreement between the simulated and measured *ETc* of maize and wheat crops at Zamklon site. (The regression equations and determination coefficients were $y = 1.0999x - 0.8194, R2 = 0.945$ and $y = 0.8526x + 0.0569, R^2 = 0.858$ for maize and wheat, respectively). For the maize crop, the difference between the observed and the simulated *ETc* was uniform during the entire growing season, and it was around ± 0.5 mm/day. For wheat, however, this difference was around ± 0.6 mm/day till the mid-season, and it increased to around ± 1 mm/day from the mid-season till the end of the season.

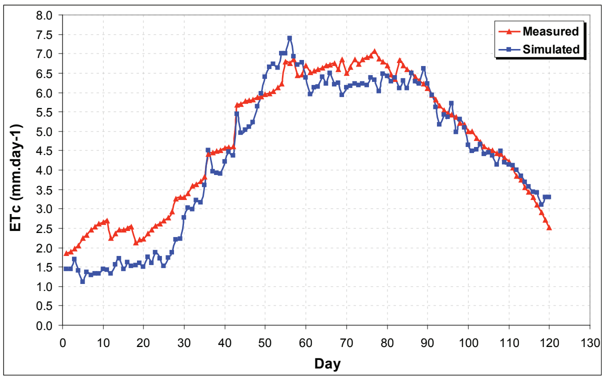

Figure 8: Mean daily simulated and observed *ETc* of maize at Zanklon, over the years 2007 through 2009.

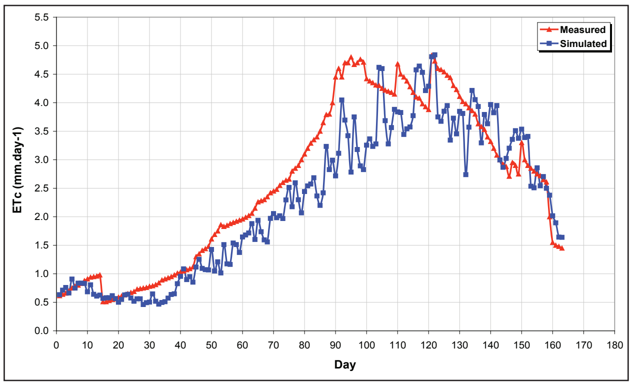

Figure 9: Mean daily simulated and observed *ETc* of wheat at Zanklon, over the years 07/08 through 09/10.

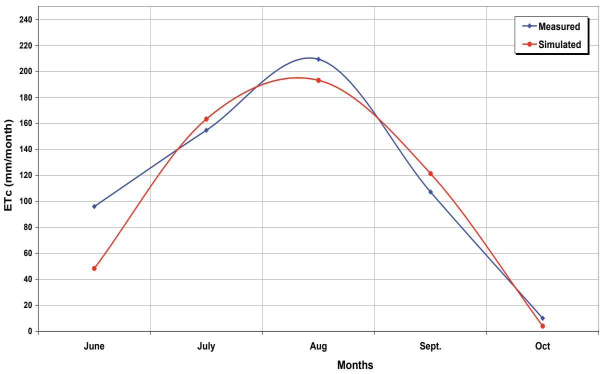

Figure 10: Mean monthly simulated and measured *ETc* of maize at Sakha over the years 2007 through 2009.

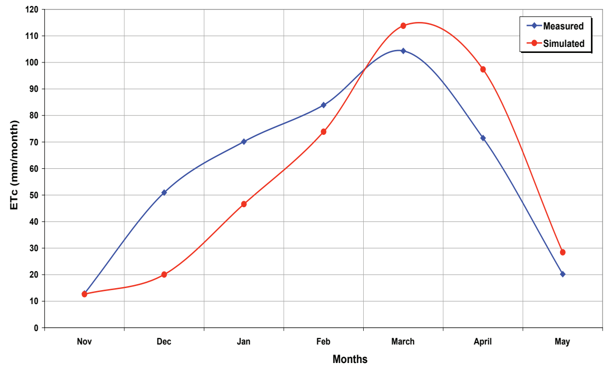

Figure 11: Mean monthly simulated and measured *ETc* of wheat at Sakha over the years 2007-08 through 2009-10.

Figures 10 and 11 show a good match between the simulated and measured *ETc* of maize and wheat crops at Sakha site. (The regression equations and determination coefficients were $y = 1.0119x - 10.783, R^2 = 0.904$ and $y = 1.0276x - 4.6561, R^2 = 0.748$ for maize and wheat, respectively). For wheat, the difference between the observed and the simulated *ETc* was around ± 0.3 mm/day. For maize, almost no difference was detected during the entire season.

Evapotranspiration of applied water (*ETaw*) calculations

The *ETaw* is calculated both on a seasonal and annual basis as the cumulative *ETc* minus the effective rainfall. The calculations are made for each year over the period of record as well as an overall average over years. Figure 12 shows the fluctuations in soil water content (SWC) between field capacity (FC) and maximum depletion during off-season and between FC and yield threshold depletion (YTD) during season for maize crop planted on June 1. Due to climate change the planting date of maize may have to be shifted (earlier) as shown in Figure 13. Figure 14 shows the relation between the same parameters for wheat crop with one planting date. As the maize crop is a summer crop, there was no rainfall in the growing season, and the crop relied completely on irrigation at SWD level of about 50% readily available water. At the current planting date (1 June), the growth season for maize was shorter than the projected earlier planting date (7 May). This results in more uniform irrigation intervals with same number of irrigation events. For wheat, three rainfall events above *ETc* values were observed at the start of the season, which increase the irrigation interval at the early stage of the season, and reduce the irrigation events.

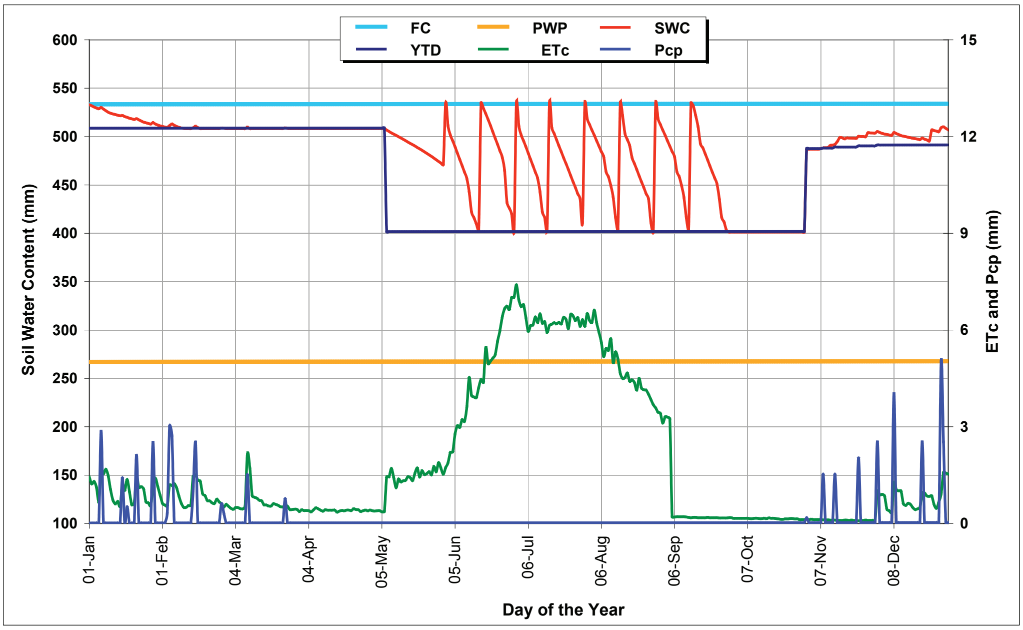

Figure 12: Annual water balance for maize showing fluctuations in soil water content (SWC) between field capacity (FC) and maximum depletion during off-season and between FC and yield threshold depletion (YTD) during summer season (planting date Jun 1, 2006 at Zanklon).

Irrigation scheduling using SIMETAW model

The daily climate data are used to compute daily *ETo* and then Kc values are used with the *ETo* to estimate *ETc*. Soil water-holding characteristics, rooting depths, and crop evapotranspiration estimates are used to determine a daily soil water balance. Then, based on the inputs for specific location, SIMETAW determines an efficient irrigation schedule for a particular crop and soil. This can be repeated for all of the cropping pattern and soil combinations within a particular region of reference evapotranspiration. In this study, irrigation scheduling is discussed for maize and wheat as the major crops in the Nile Delta.

It is obvious from Figure 15 that SIMETAW determined well when the maize should be irrigated; the model determines 8 events for maize including the sowing irrigation event at June 1, 2006. Table 7 shows the actual irrigation events dates and intervals and the simulated ones. The obtained results show a good match. The difference in the intervals of irrigation events between actual and simulated is only one day with exception of the first event (sowing irrigation). The simulated irrigation events are 8 events and the simulated first and last irrigation events dates are the same as those in actual practices.

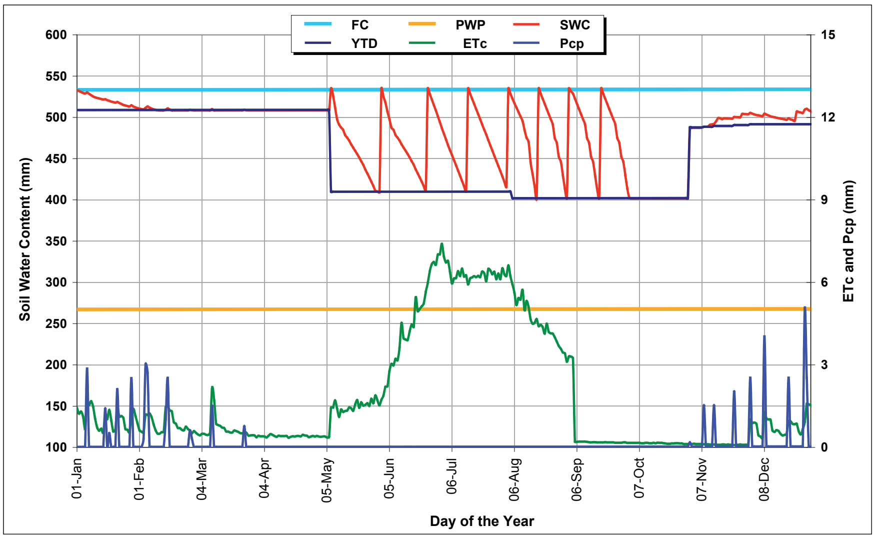

Figure 13: Annual water balance for maize showing fluctuations in soil water content (SWC) between field capacity (FC) and maximum depletion during off-season and between FC and yield threshold depletion (YTD (planting date May 7, 2006 at Zanklon).

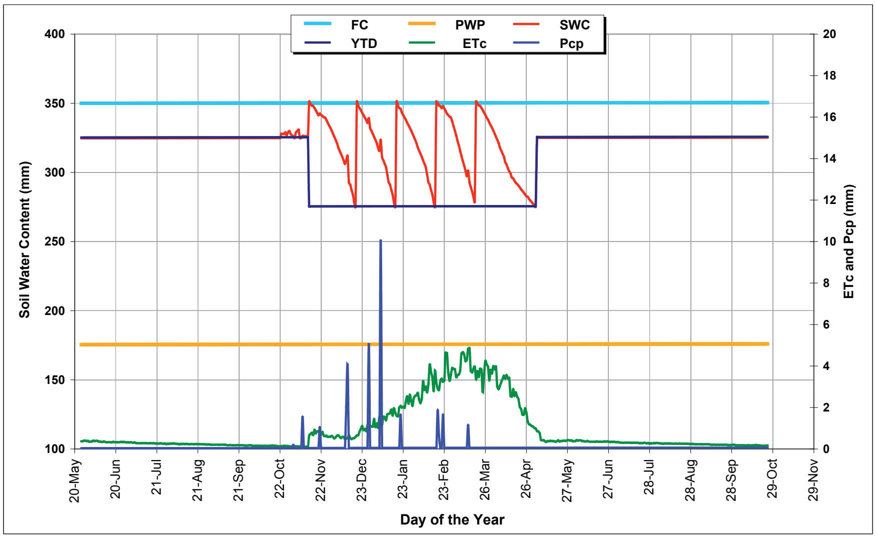

Figure 14: Annual water balance for wheat showing fluctuations in soil water content (SWC) between field capacity (FC) and maximum depletion during off-season and between FC and yield threshold depletion (YTD) (planting date Nov. 13, 2005 at Zanklon).

Table 7: A comparison between the actual and simulated irrigation events dates and intervals of maize at Zanklon site in 2006

Event No.	Irrigation date		Intervals	
	Actual	Simulated	Actual	Simulated
1	1-June	1-June	Sowing	Sowing
2	22-June	16-June	21	15
3	6-July	1-July	15	15
4	18-July	16-July	12	15
5	31-July	31-July	13	15
6	14-August	15-August	14	15
7	28-August	30-August	14	15
8	11-September	14-September	14	15
Harvest	5-October	5-October	24	21

SIMETAW determines how much water should be applied. Then, the sum of these net applications during a season provides information on how much water is needed to match the seasonal evapotranspiration to produce the crop. Clearly, a high correlation was observed between the simulated accumulated monthly *ETc* of maize and the measured values (Table 8). The highest values of *ETc* for maize were observed during July and August for both simulated and measured values. The seasonal *ETc* difference between measured and simulated values is about 6% (±35 mm).

Table 8: A comparison between the simulated accumulated *ETc* and the measured values of maize at Zanklon site in 2006

Month	ETc (mm/month)	
	Measured	Simulated
June	116	135
July	180	195
August	174	150
September	107	64
October	6	4
Total	583	549

SIMETAW also determined when the wheat should be irrigated and the model identified 5 irrigation events including the sowing irrigation. This difference in irrigation intervals is attributed to the low amount of rainfall during the growing season (30 mm), which SIMETAW considered effective rainfall that increased the soil water content. Table 9 shows the observed and simulated irrigation events dates for the wheat. The results showed a good match. There was no significant difference in intervals and dates of irrigation events between actual and simulated with exception of the first event (sowing irrigation). The model simulated the second event at 36 days after the sowing event compared to the observed 30 days. Again, the difference is attributed to the effective rainfall.

Table 9: A comparison between the actual and simulated irrigation events dates and intervals of wheat at Zanklon site in 2009/2010 growing season

Event No.	**Irrigation date**		**Intervals**	
	Actual	**Simulated**	**Actual**	**Simulated**
1	13-Nov.	13-Nov.	Sowing	Sowing
2	20-Dec.	19-Dec.	30	36
3	19-Jan.	18-Jan.	30	30
4	12-Feb.	17-Feb.	25	30
5	9-Mar.	19-Mar.	25	30
Harvesting	16-Apr.	3-May	38	45

A high correlation was also observed between the simulated monthly *ETc* of wheat and the measured values (Table 10). The highest values of *ETc* of wheat were observed during February and March for both simulated and observed *ETc*. The seasonal *ETc* difference between measured and simulated values was about 4.3% (±17 mm). These findings indicate that SIMETAW application could be used efficiently for irrigation scheduling of maize and wheat crops grown with Nile Delta characteristics.

Updating crop coefficients by SIMETAW

Crop coefficients are determined using a modified Doorenbos and Pruitt (1977) method. This method classifies the growth period in four stages as shown in Figure 15. These stages are: initial stage (date A-B), rapid stage (date B-C), mid-season stage (date C-D), and late-season stage (date D-E). The *Kc* value on date A (*KcA*) is set equal to that on date B (*KcB*). Initially, a fixed *Kc* value is assigned to the mid-season period, but the K_c values for dates C (*KcC*) and D (*KcD*) are adjustable for the percentage shading by the canopy to account for sparse or immature canopies. During the rapid growth period, between dates B and C, the K_c value changes linearly from *KcB* to *KcC*. During late season, the *Kc* changes linearly from *KcD* on date D to *KcE* at the end of the season. If the *Kc* from the linear interpolation method is less than the *Kc* for bare soil evaporation based on *ETo* and rainfall frequency, the higher *Kc* value is used. Inflection points in the *Kc* curve occur at 10% and 75% ground cover (*Cg*) and at the onset of late season (date D). The season ends when transpiration (*T*) from the crop ceases (*T* » 0).

Table 10: A comparison between the simulated accumulated *ETc* and the measured values of wheat at Zanklon site in 2009-10 growing season

Month	***ETc* (mm/month)**	
	Measured	**Simulated**
November	14	13
December	28	22
January	59	55
February	99	89
March	118	120
April	79	78
May	0	3
Total	397	380

Table 11: Crop coefficient values of multi-seasons for major winter and summer crops at Zanklon site

Crop	Starting date	Ending date	Irri. freq (day)	% to date B	% to date C	% to date D	Kc1	Kc2	Kc3
Wheat 03-04	24-Nov	10-May	30	20	45	75	0.33	1.10	0.15
Wheat 04-05	26-Nov	10-May	30	20	45	75	0.33	1.10	0.15
Wheat 05-06	18-Nov	25-Apr	30	20	45	75	0.33	1.10	0.15
Wheat 06-07	20-Nov	10-May	30	20	45	75	0.33	1.10	0.15
Wheat 07-08	19-Nov	11-May	30	20	45	75	0.33	1.10	0.15
Wheat 09-10	13-Nov	3-May	30	20	45	75	0.33	1.10	0.15
Faba bean 04-05	13-Nov	25-Apr	45	20	45	75	0.20	1.00	0.20
Faba bean 05-06	13-Nov	27-Apr	45	20	45	75	0.20	1.00	0.20
Maize 07	3-Jun	29-Sep	15	20	45	75	0.20	1.05	0.60
Maize 08	2-Jun	27-Sep	15	20	45	75	0.20	1.05	0.60
Maize 09	7-May	4-Sep	15	20	45	75	0.20	1.05	0.60

From the observations shown in Table 11, it is clear that the *Kc1* at the initial stage was 0.33, 0.20 and 0.20 for wheat, faba bean and maize, respectively. While the *Kc2* at mid-season stage reached the peak with values of 1.1, 1.0 and 1.05 for the respective crops. Then the *Kc3* at the late-season stage decreased to reach 0.15, 0.20, and 0.6 respectively. The SIMETAW simulation of *Kc* was evaluated for three crops. Based on the evaluation assumptions, *Kc* curves of wheat (Figure 15) and faba bean (Figure 16) have a remarkable fluctuations at the initial growth stages, due to rainfall effects which are not recognized in the *Kc* curves of maize (Figure 17) as there is no rainfall in summer season in Nile Delta. Thus, during early growth of crops, when considerable soil is exposed to solar radiation, *ETc* is dominated by soil evaporation and the *ET* rate depends on whether or not the soil surface is wet. If a nearly baresoil surface is wet (due to rainfall event for instance), the *ETc* rate is slightly higher than *ETo*, when evaporative demand is low, which shift the *Kc* values above the standard levels. However, as a soil surface dries off, the evaporation rate considerably decreases.

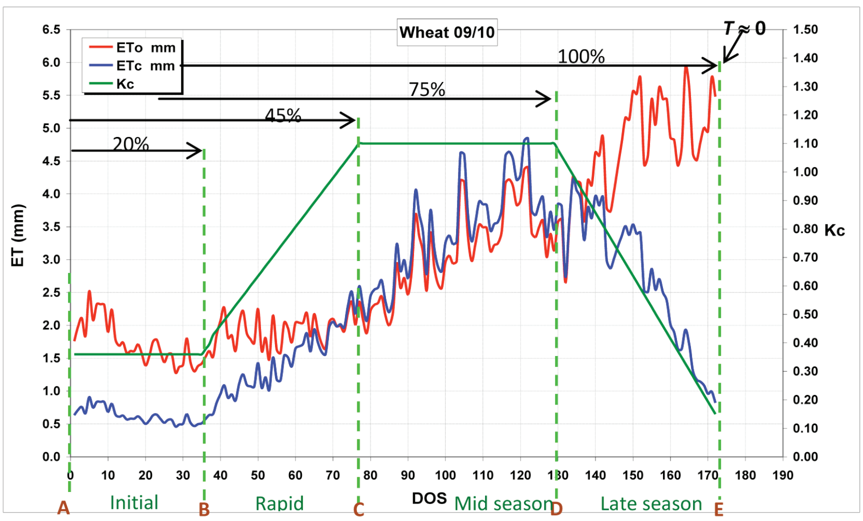

Figure 15: *ETc*, *ETo* and *Kc* evolution for wheat at Zanklon of year 2009-10.

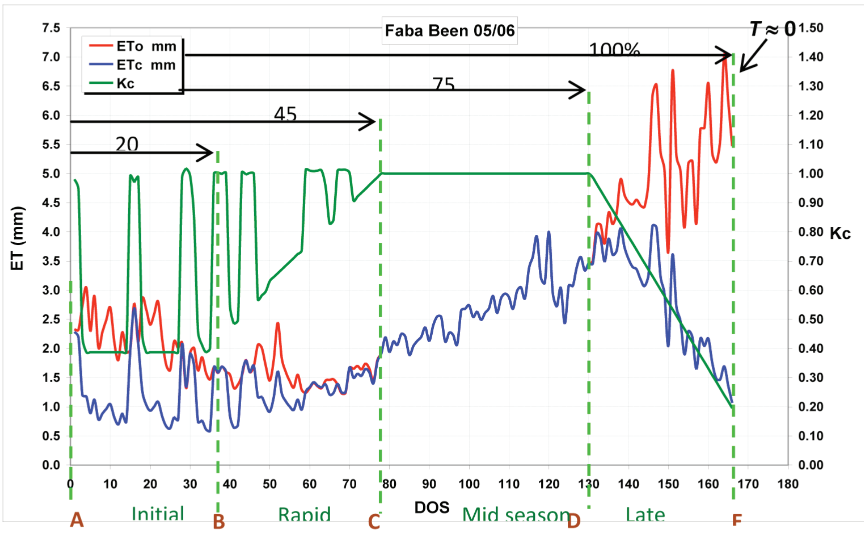

Figure 16: *ETc, ETo* and *Kc* evolution for faba bean at Zanklon of year 2005-06.

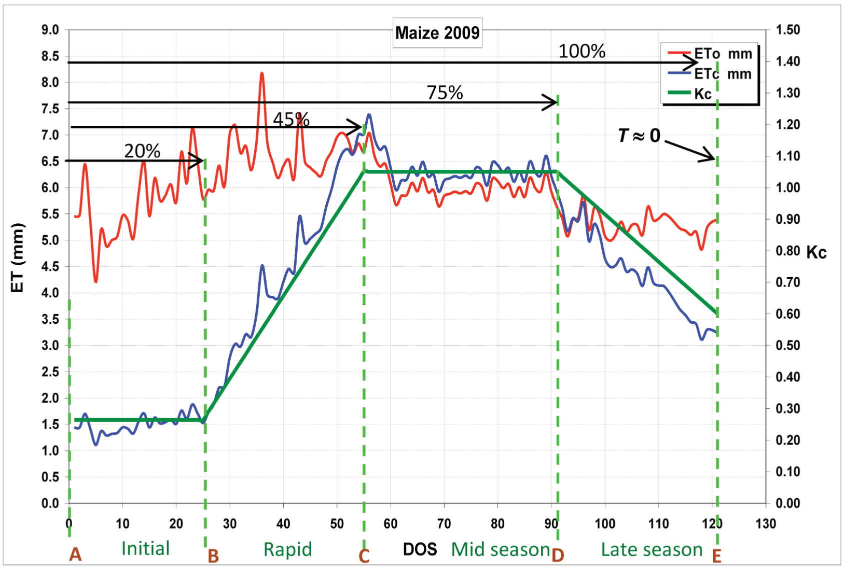

Figure 17: *ETc, ETo* and Kc evolution for maize at Zanklon of year 2009.

Conclusions

SIMETAW showed high accuracy in simulating the initial weather parameters needed for calculating *ETo*, and simulating *ETo* and *ETc* for a long time series. The accuracy of the simulation is mainly enhanced by improving the reliability of the reference observed weather date sets. Precipitation simulations by SIMETAW were less accurate than expected for the dry climate conditions of the Nile Delta. This needs further study.

Based on inputs, the SIMETAW application determined an efficient irrigation schedule for particular crops and soils. This can be repeated for all crops and soil combinations within a particular *ETo* zone. SIMETAW can provide efficient updates for Kc values and *ETc* for crops cultivated under different irrigation strategies. The updates of the *ETc* and Kc could be studied to adapt to climate change. The SIMETAW model could provide tremendous help for Egyptian irrigation engineers with limited research funding to improve their knowledge of crop water requirements.

More crop calibrations are needed to assess the effect of the inter-annual climate variability (especially precipitation and wind speed) on the model simulation accuracy. Since SIMETAW was only calibrated in the Nile Delta, further calibration in other regions such as Upper Egypt, new reclaimed lands, and oasis is recommended.

SIMETAW could be used efficiently to evaluate different irrigation strategies that support irrigation planning and improvement. Also, it could be used efficiently to evaluate the observed and the projected *Kc* values of field crops cultivated under different irrigation strategies, which can lead to better irrigation planning. In addition, with the looming possibility of climate change, it is likely that the *ETc* will change leading to *Kc* changes. It is critically important that SIMETAW model be in-place for water policy makers to update *ETc* and *Kc* values as the climate changes.

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Numerical simulation of the groundwater at sedimentary field in the Liudaogou Catchment on the northern Loess Plateau, China

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Abstract

In the Chinese Loess Plateau, construction of a check dam at downstream in a gully has been verified as an effective measure to mitigate the loss of soil and water. The alluvial plain generally has been formed due to sedimentation at the upstream-side of the check dam after 20 or 30 years since its construction. Combination of the check dam and the sedimentary field impacts on water flow in each small dam basin significantly. The shallow groundwater (phreatic water) has come into being at the sedimentary field. In the current study, field survey and hydrological observations were conducted at a sedimentary field of the Liudaogou Catchment. A numerical model for shallow groundwater calculation was developed based on kinematic wave theory and its validity was tested and verified by numerical simulation of the observed groundwater level. Result of the current study is expected to provide the basis for further studies on groundwater at the sedimentary field on the northern Loess Plateau.

1. Introduction

China's Loess Plateau is famous for its serious loss of soil and water and the fragile ecological environment (Xin *et al.* 2008). Over 60 % of the land in the Chinese Loess Plateau, one of the most severe erosion affected areas in the world, has been subjected to soil and water loss (Sun 1988). A well-proven method to mitigate the soil erosion is construction of a check-dam at downstream in a gully. By 2002, about 113,500 check dams had been built on the Loess Plateau (Xu *et al.* 2004; Xu *et al.* 2008; Zhang *et al.* 2010). The sediment transportation was spontaneously intercepted and the sediment deposited in front of the check dam since its construction. A small-scale alluvial plain (sedimentary field) has been formed at the upstream-side of the check dam after 20-30 years of the dam construction due to the sedimentation. The most of surface runoff generated at the catchment of the check dam was also intercepted along with the sedimentation. The dammed-up surface water evaporated and infiltrated into the soil and the shallow groundwater (phreatic water) generally came into being. Scale of the groundwater table gradually stabilized with the passage of time. On the other side, a comparatively stable groundwater outflow occurs at the downstream-side of the check dam.

At the northern Loess Plateau, the mean annual precipitation is only 400 mm with uneven distribution in addition to the intense evapotranspiration which causes the seasonal deficiency of water resources (Huang *et al.* 2008a; Wang *et al.* 2009). The groundwater and its outflow becomes the significant available water for the domestic use by the people and agricultural production in each small basin on the northern Loess Plateau (Huang *et al.* 2008a). The sedimentary field formed in front of the check dam demonstrably plays an important role not only in decreasing the sediment transportation but also in redistributing the surface water in each small basin.

In the current study, the research was conducted at a sedimentary field of the Liudaogou Catchment. Many researchers have conducted studies related to hydrology at the Liudaogou Catchment. Kimura *et al.* (2004) estimated the moisture availability over the Liudaogou Catchment using new indices with surface temperature; Zhu and Shao (2008) characterized variability and the pattern of upper soil moisture by field experiment; Fan *et al.* (2010) evaluated the soil water balance during vegetative restoration; Hu *et al.* (2011) characterized the spatio-temporal variability behavior of land surface soil water. Compared with the research findings on the soil water, groundwater is still poorly understood due to lack of studies even though such studies are significant for assessing the available water resources of each small catchment on the northern Loess Plateau. Therefore, in the current study, a numerical model for groundwater calculation at the sedimentary field was developed for the purpose to provide the basis for the further studies on groundwater on the northern Loess Plateau.

2. Methodology

2.1 General situation of the study location

The Liudaogou Catchment (110°21'-110°23' E longitude and 38°46'-38°51' N, latitude, area, 6.89 km^2) (Figure 1), located at the northern Loess Plateau, was chosen as the study location because it represents diversified landscape types in terms of soil morphology, hydrogeology and climate conditions, and is under a number of land-uses representative of the northern Loess Plateau. Elevation range is 1094.0 m-1273.9 m (Wang *et al.* 2006; Zhu and Shao 2008). Average annual precipitation is 437 mm with variable seasonal distribution; more than 70 % of the total is received in rainy season from June to September generally in form of several rainstorms.

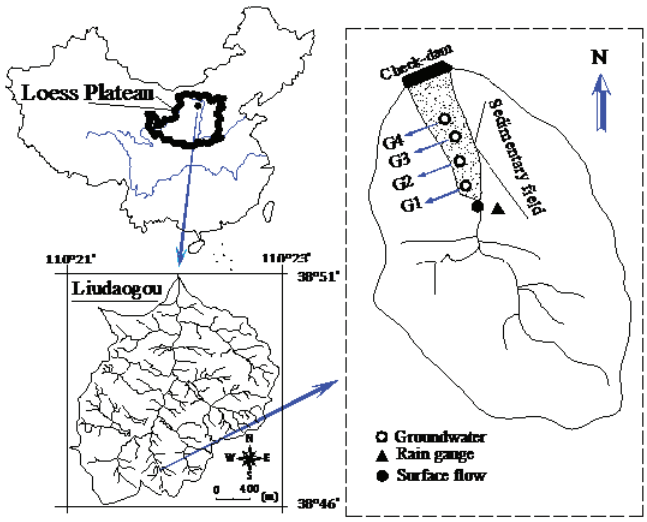

Figure 1: Position of the Liudaogou Catchment and layout of hydrological observation arrangement.

The annual available water resources are relatively low. Due to the long-term water erosion, the landform has become very complicated, many gullies in various scales crisscross within the Catchment. In the vertical profile, the topsoil is the loose loess with the thickness of about 0.10 m which has resulted in the long term wind erosion. Below the topsoil is the hard yellow ocher with the thickness of more than 20 m, and the under stratum is sandstone stratum formed in Jurassic period of Mesozoic (Fan 2005; Kimura *et al.* 2007; Huang *et al.* 2008).

The study location is a small dam basin which is located at the upstream of the Liudaogou Catchment (Figure 1). A check dam was constructed at lower end in a large gully about 30 years ago and a small alluvial plain has been formed due to sedimentation. The present plane form of the sedimentary field is approximately trapezoid. The length is 452 m in the longitudinal direction, and in the lateral direction, the width gradually increases from 8 m to 68 m from the upper-end to the lower-end (check dam) (Figure 1).

2.2 Hydrological observation

Hydrological observation on groundwater level, rainfall and surface flow was conducted at the study location. Groundwater level (phreatic water) and the depth of the surface flow were observed by water level recorder (Groundwater, HM-910-02-309, *Sensez co. ltd*.; Surface flow, KADEC21-MZPT, *KONA System co. ltd.*). As the groundwater level was relatively stable, the measurement interval was set to 1 h. Since the ephemeral runoff was significantly influenced by rain intensity, the measurement interval of the surface flow observation was set to 5 min. To estimate the surface flow, the water level data was converted into discharge data. Manning's mean velocity formula was applied to the conventional method for data transformation from water level to discharge (Equation (2); Hinokidani *et al.* 2010). Layout of the observation arrangement is shown in Figure 1.

2.3 Model development

2.3.1 Lumping model of hydro-geological conditions

Partial view of the sedimentary field and check dam is depicted in Figure 2. Based on the leveling survey along the gully (river channel), the longitudinal profile of the sedimentary field was determined as shown in Figure 3. The hydro-geological model of the study location was developed based on the results of field survey on soil vertical profile. The model was composed of the sedimentary field and slope on both sides. The slope was separated into two soil layers from the ground surface to the sandstone stratum, and modeling of the sedimentary field was considered as a single soil layer due to the uniform bedding structure of the soil profile. The sectional view of the hydro-geological model is represented in Figure 4. At the sedimentary field, the groundwater table exists at the lower soil layer. Investigation on groundwater table and the aquifer thickness was conducted by digging the small bore wells (diameter: 5 cm) using the earth boring auger. The inflow components at the sedimentary field are the surface flow, subsurface inflow and rainfall. The surface inflow was given as ephemeral flow from the upstream region, the surface inflow from the surrounding slopes and the rainfall. The subsurface inflow components are the subsurface inflow from the first and the second layer from the slope. The outflow components are the surface runoff, the groundwater outflow at downstream-side of the sedimentary field (Figure 3), the evapotranspiration and the infiltration into the sandstone stratum (Figure 4).

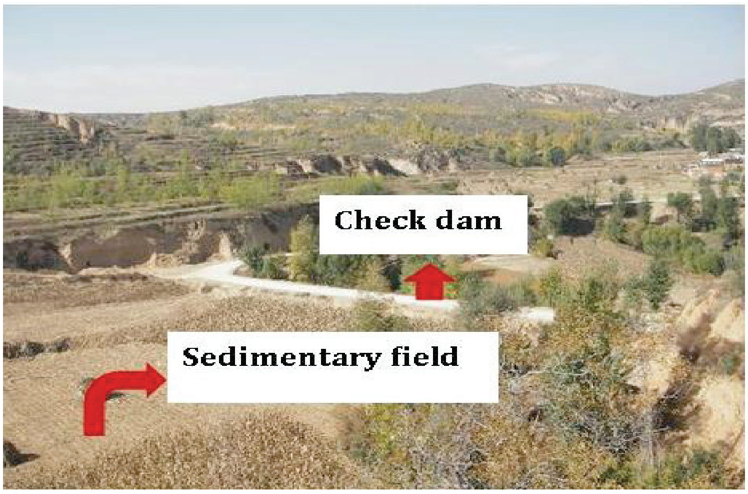

Figure 2: Partial view of check dam and sedimentary field.

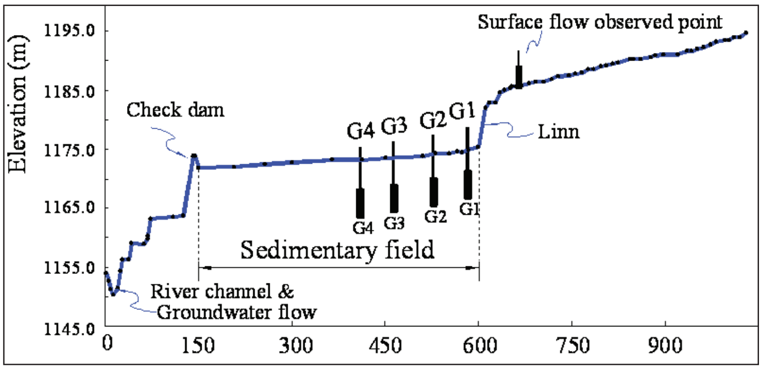

Figure 3: Longitudinal profile of the sedimentary field.

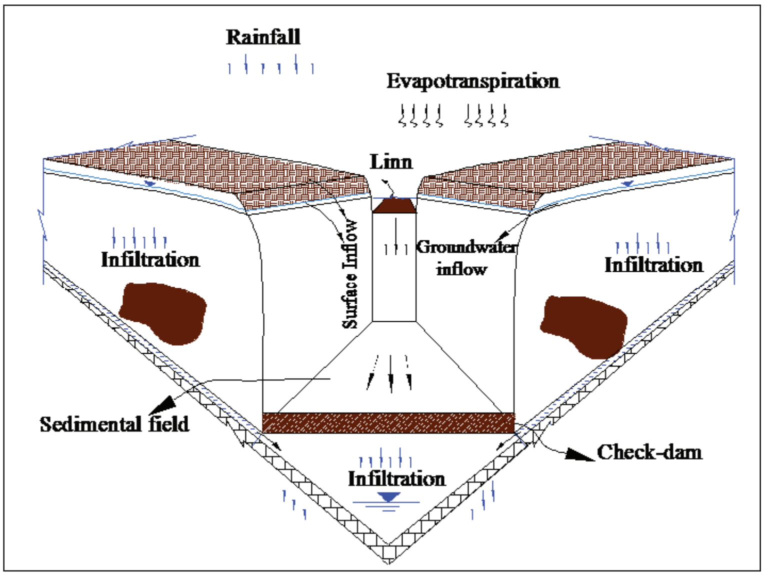

Figure 4: Sectional view of lumping model of hydro-geological conditions.

2.3.2 Governing equations

Equations used in the calculation at the sedimentary field are given as follows.

- Continuity equation of the surface flow

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=(r-f_1)B+q^{,} \qquad (1)$$

- Manning's average velocity Equation

$$Q=\frac{1}{n}AR^{\frac{2}{3}}I^{\frac{1}{2}} \qquad (2)$$

- Continuity equation of the groundwater flow

$$\lambda\frac{\partial \overline{A}}{\partial t}+\frac{\partial \overline{Q}}{\partial x}=(f_1-ET-f_2)B_g+q^{*} \qquad (3)$$

- Darcy's formula

$$\overline{Q}=kI_g\overline{A} \qquad (4)$$

- Sectional area of groundwater flow

$$\overline{A}=\frac{1}{2}B_gH_g \qquad (5)$$

where, A is sectional area of the surface flow (m^2), dt is unit time (s), Q is flow discharge (m^3/s), dx is unit length in the flow direction (m), r is rainfall (m/s), n is coefficient of roughness ($sm^{-1/3}$), B is width of the river channel (m), R is hydraulic radius (m), I is gradient of channel, $q^{,}$ is inflow from the slope, it is the sum of the surface flow and the groundwater flow in the first layer from the slope (unit discharge: $m^2 \cdot s^{-1}$), f_1 is mean infiltration velocity of the soil layer (m/s), λ is the effective porosity of soil, $\overline{A}$ is sectional area of the groundwater flow (m^2), k is coefficient of permeability (m/s), I_g is gradient of groundwater table, f_2 is the mean infiltration velocity from the soil to weathered sandstone stratum (m/s), ET is evapotranspiration (m/s), q^* is groundwater inflow from the second layer in slope (unit discharge: $m^2 \cdot s^{-1}$), B_g is width of groundwater table (m), H_g is depth of groundwater (m).

The equations for the slope are similar to those of the sedimentary field. Only some factors in equations were replaced which resulted in variation of the equations in forms.

2.3.3 Differentiation scheme

As the governing equations characterize transfer of the boundary condition at the upper to down side, the upstream-difference scheme was used (The Japan Society of Mechanical Engineers: Fundamentals of Computational Fluid Dynamics, 1988). The continuity equation of the surface flow (**Eq. 1)** and the continuity equation of the groundwater flow (**Eq. 3)** were differentiated as follows:

$$A_i^{n+1}=A_i^n+dt\cdot\left[(r-f_1)B+q^{,}-\frac{Q_i^n-Q_i^{n-1}}{dx}\right] \qquad (6)$$

$$\overline{A}_i^{n+1}=\overline{A}_i^n+\frac{dt}{\lambda}\left[(f_1-ET-f_2)B_g+q^{*}-\frac{\overline{Q}_i^n-\overline{Q}_i^{n-1}}{dx}\right] \qquad (7)$$

where, n is time step of calculation, i is grid number, other factors are same to the above mentioned. The calculation for the next temporal moment (n+1) at the current grid (i) depends on the results of the current moment (n) of the current grid and the current moment of the up-site grid (i-1). The continuous spatial-temporal calculation therefore can be ensured from the upstream ends of the slope and sedimentary field in the flow direction. The numerical model was developed by FORTRAN 95, the actual process of program compiling was omitted here.

2.3.4 Evapotranspiration

The vegetation type on the sedimentary field is mainly grass (natural meadow) except the lower edge. At the lower edge near the check dam, field crops were grown during the vegetative growing season. In the process of calculation, evapotranspiration over grassland was used as whole evapotranspiration at the sedimentary field in the model. Evapotranspiration over grassland was calculated by Penman-Monteith equation (Allen *et al.* 1998) which has already been proved to be a suitable method to calculate the evapotranspiration at the Liudaogou Catchment (Kimura *et al.* 2005).

$$lET = \frac{\Delta(R_n - G) + c_p \rho \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \dfrac{r_s}{r_a})} \qquad (8)$$

where, lET is the latent heat flux ($MJ \cdot m^{-2} \cdot h^{-1}$), Δ is the slope of the saturation vapor-pressure at air temperature ($kPa \cdot {}^{o}C^{-1}$), R_n is net radiation ($MJ \cdot m^{-2} \cdot h^{-1}$), γ is the psychometric constant ($kPa \cdot {}^{o}C^{-1}$), G is soil heat flux ($MJ \cdot m^{-2} \cdot h^{-1}$), e_s is saturated vapor-pressure at air temperature (kPa), e_a is actual vapor-pressure (kPa), c_p is the specific heat of the air ($MJ \cdot kg^{-1} \cdot {}^{o}C^{-1}$), ρ is the air density at constant pressure ($kg \cdot m^{-3}$), r_a is the aerodynamic resistance ($s \cdot m^{-1}$), r_s is surface resistance ($s \cdot m^{-1}$).

The data used in the calculation of the evapotranspiration were daylight duration, temperature, wind speed, specific humidity and mean soil water content. The observational depth of the soil water content was at the 4, 10, 26, 34, 42, 50, 58, 66 and 100 cm. The required data for Eq. 8 was obtained at a meteorological station which was set up on the slope near the check dam.

2.3.5 Parameters

The parameters of the model were given by field survey and the previous studies which conducted at the same study location, such as the gradient of slopes was obtained by land leveling survey, thickness of the soil layer was given by field measurement. Some parameters related to the soil hydraulic properties such as infiltration velocity, coefficient of roughness and permeability were presented by referring to a previous study on the Liudaogou Catchment (Huang et al. 2008b). The main parameters are listed in Table 1.

2.4 Model validation

Validity of the model was tested and verified by numerical simulation of the observed results of the groundwater level (Observation points: G1-G4 in Fig. 1). The year of 2006 was chosen for

Table 1: Main parameters

Parameter	Sedimentary field	Slope		Unit
n	0.06	0.10		s·m$^{-1/3}$
Thickness	Varies from upper end to lower end	1st	0.20	m
		2nd	20	
λ	0.32	1st	0.35	……
		2nd	0.25	
k	1.6×10^{-4}	1st	1.0×10^{-3}	m·s^{-1}
		2nd	3.0×10^{-5}	
f	2.8×10^{-6}	1st	3.0×10^{-6}	m·s^{-1}
		2nd	2.0×10^{-7}	
	Weathered sandstone stratum	1.2×10^{-8}		

calculation and the observed data of groundwater level was unavailable from 15 November to the yearend. The simulated results were shown in Figure 5, which shows that the calculated results reproduce the observed one well. Reliability of the model was verified through test of goodness of fit of the simulation results. Coefficient of determination (R^2) of the simulation result at each observed point was more than 0.92. The model therefore reconstructs conditions of groundwater flow at the sedimentary field in a satisfactory way.

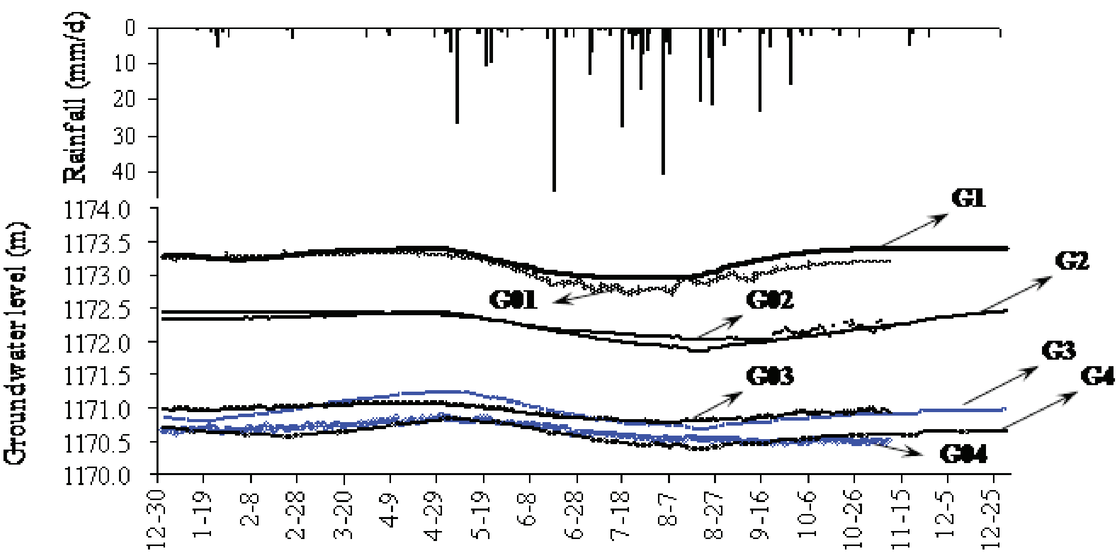

Figure 5: Simulation results of the groundwater level (G01-G04: Observed results, G1-G4: Calculated results).

3. Conclusions

The developed numerical model was applied to groundwater calculation at the sedimentary field in the Liudaogou Catchment. As the hydro-geological conditions are similar at each sedimentary field formed at the upstream-side of check dam the model can be popularized for assessing the groundwater on the northern Loess Plateau.

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Impact of use of drainage on water delivery performance in irrigation networks at the lower Nile Delta

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Abstract

The main problem facing the Nile Delta water supply is shortages at the ends of irrigation networks as well as at the ends of main canals. This problem has become accentuated as water demands have increased over time. The Ministry of Irrigation and Water Resources of Egypt is currently trying to avoid water supply shortages by feeding irrigation canals through an agricultural drainage system. However, there is an oversupply in some months and shortages in others. Therefore, we calculated performance indicators (adequacy, efficiency, dependability and equity) for an area in the Kafr El-Sheikh Governorate under two water supply conditions: (1) water supply from head regulators only (WSHR) and (2) water supply from head regulators supplemented by backflow from agricultural drainage canals (WSHRB). During the summer (May–September) of 2008, WSHR was sufficient during May and September for all branch canals. It was insufficient during June, July and August, and supplemental agricultural drainage backflow was required. During the following winter (October–April), WSHR was sufficient during all months in all branch canals, so there was no need for agricultural drainage backflow during these months. The amount of drainage backflow was more than sufficient to supplement the freshwater shortage during June, July and August. If the quality is sufficiently high, drainage backflow may have the potential to conserve freshwater flowing from canal head regulators or to increase the area under cultivation.

Introduction

Water is essential to life, but it is a limited resource that must be protected. The aim of water management is to develop and protect available water and land resources. In water-scarce countries such as Egypt, which depends on external water supplies, water distribution to different water users is of paramount importance. Egypt is an arid country with little rainfall. It mainly depends on the supply of freshwater transported from Nile basin countries through the Nile River, but the river water resource is under increasing stress because of increasing competition for available water. Irrigation needs have expanded, as have domestic and industrial water needs because of population and industrial growth.

The Ministry of Irrigation and Water Resources is responsible for planning, construction, operation, management and maintenance of the irrigation and drainage network in Egypt. Apart from natural groundwater supplies in oases and the limited rainfall along the Mediterranean coast, agriculture in Egypt is entirely dependent on surface irrigation with waters from the river Nile. The construction of the High Dam at Aswan in Upper Egypt close to the border with Sudan, completed around 1968, had a great impact on the irrigation and drainage situation in Egypt. On the one hand it increased the availability of irrigation water to some 46 billion m3 per year. On the other hand, the intensified irrigation has led to a rise of water tables, drainage problems, and an increased salt import into the agricultural lands.

Preliminary studies indicated that there is a water supply shortage for both IIP project areas of El-Wasat (31,500 hectare) and El-Manaifa (19,740 hectare) in Kafr El-Sheikh Governorate. It is proposed to substitute shortage in fresh water supply from the available drainage water within the project areas, which could be mixed with canal fresh water at proper locations. The mixture should be within pre-determined quality limits that takes into consideration the long-term effect on the soils and crops in both areas. The study aimed at monitoring and defining the available drainage water resources and its quality in both project areas. The negative impacts on agriculture due to drainage water reuse have to be kept minimum.

Main problem facing the Nile delta is water supply shortage at the end of irrigation network especially at the tail of main canals branched from Nile River; nowadays the government depends on feeding some

canals which have water supply shortage from the drains. In this study, a pipe was constructed at the end of the branch canal to feed it whenever there is water shortage. But backflow conveyed from the drain to the canal depends on water level differences between drain and canal tail. That is because the water structure (pipe) connecting the end of the canal with the drain does not have control gates or valves. It is only to convey water from the drain into the canal whenever the drain water is higher.

Main objectives of this study are to check water distribution performance for the study area which face water shortage and depend mainly on water backflow from the main drain (BhrNashart). The performance of the study area was checked with and without backflow from the drain.

Materials and methods

Adequacy, Efficiency Dependability and Equity indicators were calculated for the study area within two situations: 1) Water supply from Head Regulators (WSHR) and 2) Water supply from Head Regulators plus Backflow from the agricultural drainage canals as an additional supply (WSHRB). For this evaluation, some data were required from the field to calculate the indicator: water levels, gate openings, discharges, pipe dimensions connecting channels with (BhrNashart) drain and crop pattern. These were measured from May 2008 to May 2009 by The Water Management Research Institute (WMRI) of the National Water Research Center (WMRI 2008). Calculations of daily water supply in the head of branch canal depend on calibration of head regulator, which required data on water levels at upstream, downstream and gate opening of head regulator. Calculation of daily backflow from the drain depends on calibration of pipe connecting canal with drain (DCM 2001; HEC-RAS 2008) which requires data on tail water levels, drain levels and pipe dimensions. Calculation of water demand is based on CROPWAT model (FAO 1992).

Performance indicators

The following indicators (Table 1) were used to describe the system performance:

Adequacy: it can be defined as the ability of an irrigation system to meet the required irrigation water:

$$P_A = \frac{1}{T}\sum_{T=1}^{T}\left(\frac{1}{\mathrm{R}}\sum_{R=1}^{R} P_A\right)$$

where P_A on the right is calculated as Q_D/Q_R. When the amount delivered (Q_D) exceeded the amount required (Q_R), the amount delivered was accepted as adequate without considering the amount of the excess, and the ratio Q_D/Q_R was taken as 1.00. A value of 1.00 or close to 1.00 for P_A showed adequacy of water delivery, while a value less than 0.80 for P_A showed inadequacy of water delivery. T represents the time period in which system performance was determined and R represents the sub region of the system whose performance is to be determined.

Efficiency: It embodies the ability to conserve water by matching water deliveries with water requirements:

$$P_F = \frac{1}{T}\sum_{T=1}^{T}\left(\frac{1}{\mathrm{R}}\sum_{R=1}^{R} P_F\right)$$

where P_F was calculated as Q_R/Q_D. When $Q_R \leq Q_D$, the value of P_F was calculated, but otherwise it was taken as equal to 1.00. P_F was equal to or near to 1.00 indicated that water in the system was being used efficiently, but if the value was less than 0.70, it meant that water in the system use was not efficient.

Dependability: It expresses the ability to find water at the time and place desired in the system:

$$\mathrm{P_D} = \frac{1}{\mathrm{R}}\sum_{\mathrm{R}=1}^{\mathrm{R}} \mathrm{CV_T}\left(\frac{\mathrm{Q_D}}{\mathrm{Q_R}}\right)$$

where CVT (QD/QR) = coefficient of temporal variation of the ratio QD/QR in time period T. When the value of PD approaches zero, water delivery for the time period under consideration is shown to be uniform and thus more dependable.

Equity: It expresses the degree of variability in relative water delivery from point to point over the irrigated area:

$$P_E = \frac{1}{T}\sum_{T=1}^{T} CV_R\left(\frac{Q_D}{Q_R}\right)$$

where CV_R (Q_D/Q_R) = coefficient of spatial variation of the ratio Q_D/Q_R in area R. Equity in water delivery is shown to be greater when P_E approaches zero.

Table 1: Performance indicators

	Good	Fair	Poor
Adequacy	0.90 - 1.00	0.80 - 0.89	< 0.80
Efficiency	0.85 - 1.00	0.70 - 0.84	< 0.70
Dependability	0.00 - 0.10	0.11 - 0.25	> 0.25
Equity	0.00 - 0.10	0.11 - 0.25	> 0.25

Water supply

The calculations of water supply for the study area included both flow from head regulators at the beginning of each canal and backflow from the drain. Gate opening and water levels measurements at head regulators both upstream and downstream of the head regulators were measured daily in order to calculate inlet discharges. In addition to water levels at canals tail, drain and pipe data connecting the canal with the drain in order to calculate backflow from the drain.

Cropping pattern

The cropping pattern data of the monitored branch canals for the two main growing seasons covered by this study (summer 2008, winter 2008/09) were collected from agricultural directorates. Calculation of water demand is based on CROPWAT model (FAO 1992).

Results and discussion

Water supply

Establishments of the gate calibration depend on data point of discharge measurements on branch canals. For Masharqa canal it was calibrated as unrestricted flow condition, and for Safsaf and Eliwa canals it was calibrated as submerged flow condition.

Safsaf canal entrance gates caliberation was done using the following measurements: daily head difference, gate opening measurements and actual discharge for some selected days. The formula $y=0.91x+0.4498$ was derived where y is discharge divided by head difference and x is gate opening. Daily discharge measurements wre used to compute monthly discharges for Safsaf canal. The analysis was repeated for both Eliwa and Masharka canals and the following two equations were respectively obtained $3.1676x + 0.1074$ and $y = 0.0863e^{1.521x}$. The calibration for the three branch canals was repeated in the winter season and the following equations were obtained respectively $y = 2.2143x - 0.441$, $y = 1.4768x + 0.3322$, $y = 0.0228e^{2.3607x}$.

Backflow supply calculations

The water levels data at both canal and drain are known, in addition to pipe connecting the canal tail with drain data. Backflow discharge was calculated as daily measurements for the three branch canals during summer season 2008 and winter season 2008/09

Water requirements

Cropping pattern, data were collected from different agricultural directorates of canal command area (Figure 2).

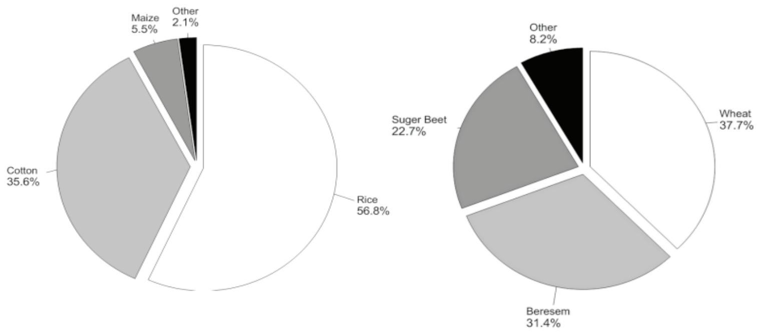


Figure 2: Cropping pattern in the study area in summer and winter

The theoretical crop water requirements of the canals were calculated for comparison with the actual supply. Planting dates for these crops were obtained from different agricultural cooperatives of canal command area. Climatic data were obtained from the records of the Sakha station. Every one month irrigation requirements were calculated using CROPWAT (FAO 1992). In this software, reference evapotranspiration (*ETo*) is calculated using the Penman–Monteith method (Table 2).

The total seasonal crop water requirement per hectare per season for the monitored branch canals for rice crop ranged around 8505 m^3, for cotton 8509 m^3, for maize 4920 m^3, for Alfalfa 4434m^3, for wheat 3484 m^3/ and for sugar beet 3528 m^3.

Table 2: Monthly water requirement of different crops

	Water requirements (m^3/ha/month)								
Season	**Winter**					**Summer**			
Crop	**Alfalfa**	**Wheat**	**Sugar Beet**	**Other**		**Cotton**	**Rice**	**Maize**	**Other**
Jan	391	379	498	416					
Feb	521	633	683						379
Mar	826	1017	1011			300			829
Apr	1031	902	494			774			1328
May	366					1636	1575	478	731
Jun						1999	1881	1039	1177
Jul						1914	1943	1765	1461
Aug						1414	1833	1648	1600
Sep						474	1274		690
Oct	414		252	591					
Nov	613	387	344	598					
Dec	320	204	294	365					

Figure 3 shows relation between water supply from head regulators, backflow supply and water requirements for three branch canals during summer 2008 and winter 2008/09.Two comparisons should be noticed, the first comparison is between water supply from head regulator and irrigation water requirements, and the second one between water supply from head regulators summed to backflow supply with irrigation water requirements.

In summer season there was a shortage in water supply from head regulators for the three branch canals in June and July which indicated the need for additional backflow supply only during these months to achieve water requirements. There was an excess water supply from head regulators in September which indicated the possibility of using this additional water supply and backflow supply at some other places. During May and August the water supply from head regulators covered the water requirements so in this case there is no need for any additional backflow supply.

In winter season there was an excess water supply from regulators for all branch canals which indicated that the backflow supply was not needed xcept for Masharka canal during March and April because of its location at the tail of the study area. It was noticed that water supply was at its minimum value during March and February because of winter closure.

Performance indicators

Performance indicators were calculated for both summer season 2008 and winter season 2008/09 as spatial and temporal.

In summer season 2008 Adequacy was good for both Safsaf and Masharka canals at WSHR and poor for Eliwa canal (Figure 4) which indicate that there is no need for backflow for Safsaf and Masharka canal. Adequacy was poor at June, July and August which state the requirements for back flow only at these months to improve Adequacy indicator. Witht WSHRB Adequacy indicator was good for all canals during summer season months which mean the positive effect of backflow. It was observed that the highest value for adequacy was at May and September, because of the lowest water requirements.

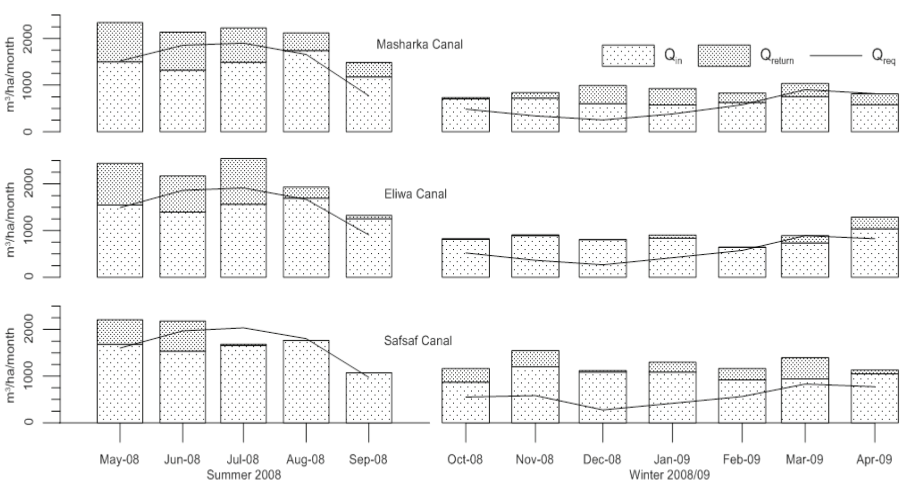


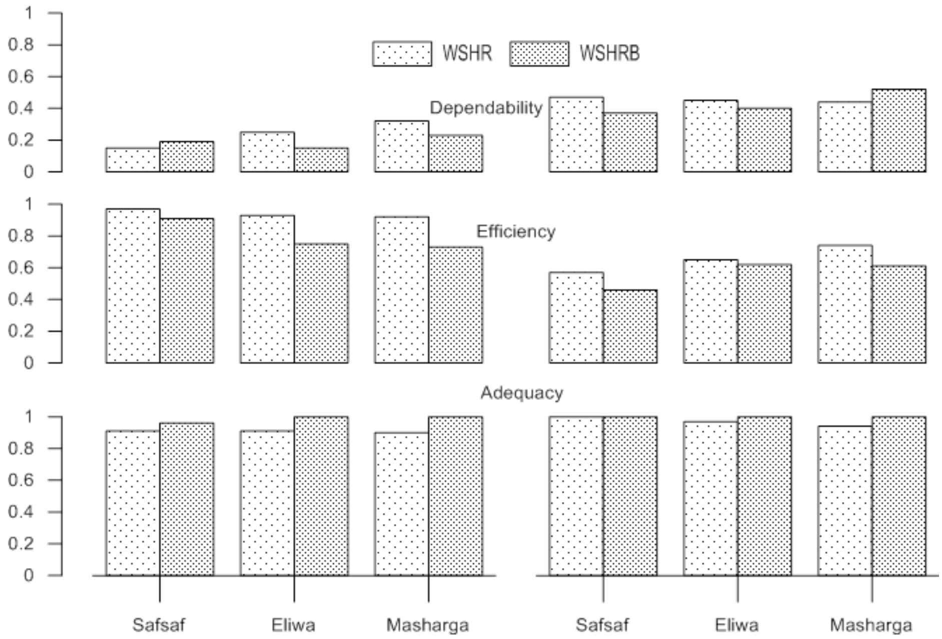
Figure 3: Water supply from head regulators, backflow supply and water requirements for three branch canals during summer 2008 and winter 2008/09.

In winter season 2008/09 it was observe mainly that water supply is higher than water requirements which leads to high values of adequacy indicator as spatial and temporal and low values for efficiency for the study area.

Backflow flowing from the drain to the canal should be controlled and distributed among the canals according to shortage in discharges, which occurred only in June, July and August. To improve the performance of the irrigation network, the pipe connecting the drain to the canal tail should be controlled by valves or replaced by pumps to allow water to flow under control. Amounts of backflow which covered and exceeded water shortage in fresh water supply can be used (if quality is appropriate) to save more fresh water flowing from canal head regulator or for increasing cultivated area. Also head regulators should be rehabilitated to allow more organized water distribution. Farmer's attitude while diverting water to their farms should be improved as usually farmers at head canals take water more than enough which leads to shortage at canals tail.

Table 3: Performance indicators for summer 2008 and winter 2008/09

Indicator	Summer 2008		Winter 2008/09	
	WSHR	WSHRB	WSHR	WSHRB
P_A	0.89	0.96	0.97	1.00
P_F	0.94	0.76	0.65	0.56
P_D	0.34	0.21	0.45	0.43
P_E	0.24	0.42	0.18	0.18



Summer 2008 Winter 2008/09

Figure 4: Performance indicators for summer 2008 and winter 2008/09 for different branch canals.

Conclusion and recommendations

This study aimed to check the water distribution performance for irrigation networks in Egypt facing shortage at the end of canals. The performance of the study area was checked with and without backflow from the drain. Backflow conveyed from the drain to the canal depends on water level differences between drain and canal tail. That is because the water structure (pipe) connecting the end of the canal with the drain does not have control gates or valves. It is only to convey water from the drain into the canal whenever the drain water is higher. Water supply was little higher than water requirements in September because of less water requirements in this month. In summer season the water supply from head regulators was sufficient during all months for all branch canals except in June and July. Backflow occurred for all canals in May while there was water supply sufficiency from head regulator in this month. Backflow occurred in the months which have water shortage but it was higher than water shortage which may affect the quality negatively. Backflow is required only in June and July so there is no need for backflow in the other months.

Water supply was less than water requirements in March because of high water requirements in this month. In winter season the water supply from head regulators was sufficient during all months for all branch canals except in March. Backflow occurred for all canals during all months while there was water supply sufficiency from head regulator. Based on the results of this research, the following main points are recommended for future investigation. Backflow flowing from the drain to the canal should be controlled and distributed among the canals according to shortage in discharges at each canal during the season to maximize the performance indicators. The farmers should decrease the area cultivated with rice as it is considered as maximum water consumption crop cultivated in the study area.

Acknowledgements: Thanks are due to the Water Management Research Institute (WMRI) for providing the necessary data for this study.

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A study on agricultural land and water management against decrease of irrigation water supply - a case study of the lower Ili River basin, Kazakhstan

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Abstract

In the lower Ili River basin where climate is arid, large irrigated agriculture has been practiced since 1960's. Rising temperature and decreasing precipitation in Central Asia are predicted by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). If the prediction happens, discharge of Ili River in summer season might decrease due to the decline of glacier area in the headwater region. In the irrigation district, a crop rotation system which combines paddy rice and field crops is practiced. Field crops use groundwater which has gone up to the root zone because of seepage from canals and paddy fields. If groundwater level falls because of decreasing irrigation water supply due to shortage of Ili River discharge, current irrigation methods might be unsustainable. It is therefore necessary to introduce appropriate management measures for control of groundwater level. As a first step towards the management of groundwater level, this study analyzed temporal and spatial distribution of groundwater level fluctuation. Additionally, it analyzed the condition of water supply to field crops by seepage from canals and paddy fields. The results are: (1) The distribution of groundwater level fluctuation was not uniform and fluctuating factors were different according to the location in the irrigation district; (2) The condition of water supply to field crops was affected by the position rather than the area of paddy fields. In response to reduction of irrigation water supply in the future, a revision of amount of irrigation water requirement, which currently is uniform to all paddy fields, for each location of paddy fields based on the spatial distribution of the paddy fields inside of the irrigation district, will be required.

Introduction

Irrigated agriculture has important role for food production and economy. The area of irrigated agriculture has risen sharply in recent years. While area of irrigated agriculture is about 28 % of the world's total farmland, irrigated agriculture produces 60 % of the total cereal production (Black and King 2010). In the former Soviet Union, many large-scale irrigation projects were established from 1960s (Funakawa *et al.* 2007). Thus, Central Asia was covered with large irrigation schemes serving a total of about 8.0 million ha of irrigated cropland (Iskandar *et al.* 2006). Nowadays, the area of irrigated agriculture is about 10 million ha in Central Asia (Bucknall *et al.* 2003). In the Republic of Kazakhstan, more than 10 million ha of grass land was transformed into agricultural land under the Soviet Union policies but at present the area of irrigated agriculture is 2.3 million ha. In the Lower Ili River Basin which is located in southeast of Kazakhstan, large-scale irrigated agriculture associated with rice-based agriculture has been developed since 1960s. The total area of irrigated agriculture is about 30 thousand ha in the Lower Ili River Basin.

In Central Asia, the irrigated agriculture uses 90 % of the 140-160 km^3 of water resources of the region (Iskandar *et al.* 2009). In Aral Sea Basin, irrigation extractions from Syr-Darya and Amu-Darya rivers that inflow into Aral Sea have contributed significantly to the problems of shrinkage of Aral Sea. Lake Balkhash is the fifth largest isolated reservoir in the world (Propastin 2011).

Water environment of Lake Balkhash is affected by Ili River because its discharge accounts for 80 % of inflow to Lake Balkhash. While construction of a water storage reservoir “Kapchagai Dam” on the Ili River in 1970 was followed by a dramatic decrease in the Lake Balkhash water level, changes to an increased water level occurred in the early 1990s (Propastin 2011). Discharge of Ili River is affected by natural factors and anthropogenic factors. Main natural factors are precipitation and temperature in upper part (Tien Shan mountains area) of Ili River basin.

Rising temperature and decrease of precipitation in Central Asia are predicted by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). Climate change might affect glacier areas in upper part of Ili River Basin. Actually, glacier areas decreased by 9-19 % in 1970-2000 in Tien Shan mountains. Mountains glaciers contribute part of this important water resource. Glaciers collect solid precipitation in winter and release this precipitation as meltwater in summer (Hagg *et al*. 2007; UNEP 2007). Main anthropogenic factors are discharge regulations by Kapchagai Dam and water withdrawal by irrigated agriculture in Kazakhstan. In addition to these factors, China, which is located in upper part of Ili River, has developed irrigated land and constructed reservoirs. In case that amount of inflow to Kazakhstan decreased because of the increasing water demand in China, the water withdrawal for irrigation will have to be decreased to protect water environment of Lake Balkhash. However Kazakhstan government seeks bilateral talks with China about water use adjustment on Ili River, although the issue is showing little progress. Due to excessive water supply to irrigated land and inadequate water and land management in irrigation districts, land salinization has occurred and become a huge issue. Area affected by salinization is 47.5 % of total irrigated land in Central Asia. In Kazakhstan, the area is more than 33 % of total irrigated land (Bucknall *et al*. 2003).

The characteristics of water supply to irrigated agriculture associated with rice-based agriculture in Central Asia are as follows: a) Irrigation of fields is done only once or twice during early stage of growth; b) Continuous irrigation is practiced in rice cropped fields while irrigation to fields is not practiced; and c) Field crops use groundwater which has gone up to the root zone by seepage from unlined canals and cropped rice. While groundwater has role for water supply to field crops, excessive rising of groundwater level induces secondary soil salinization. As previously mentioned, there is a possibility of decreasing amount of water withdrawal for agriculture in Lower Ili River.

Decreasing irrigation water supply due to shortage of Ili River discharge will cause decrease in the amount of seepage from rice cropped fields and unlined canals. In that case, groundwater level will fall and current irrigation methods might not continue. It is therefore necessary to introduce appropriate agricultural land and water management measures for control of groundwater level. The paper describes analysis of groundwater level fluctuation and condition of water supply to fields. The analysis is a first step towards the management of groundwater level. Finally, the paper focuses on conclusions and recommendations for agricultural sustainability and adequate water resources management on Ili River Basin.

Materials and methods

Outline of study area

The study area is located in the south side of Akdara irrigation district (15 thousand ha) in the lower reach of Ili River in southeast Kazakhstan (Figure 1). Annual mean temperature is about 9^{o} Celsius and mean temperature in irrigation period from May to August is about 24 ^{o} C. Annual precipitation is only 150 mm/yr and monthly precipitation is only 10 mm. Annual potential evapotranspiration is 1157 mm/yr and potential evapotranspiration in irrigation period is 736 mm/period.

During the Soviet era, agricultural activity was conducted by *sovhoz* which is national farm and *kolkhoz* which is collective farm. Necessary equipment was supplied by the government and agricultural produce was returned to government. However after collapse of the Soviet Union, sovhoz and kolkhoz became cooperative farms and many privatized. The farms were therefore required to do all agricultural activities by themselves from procurement of equipment to selling of agricultural produce.

The current farm size is about 1 to 2 ha, and farm block (about 100 ha) is formed by gathering the fifty farm lots. Basically, one crop is cultivated per farm block. Main crops are rice, alfalfa, and wheat and a 6 to 7 year crop rotation is practiced which contains rice for 3 years and other crops for 3 to 4 years in one crop rotation block. The rice was included in the crop rotation not only because of it being a cash crop but also due to its effectiveness in leaching out salts which accumulate during crop cultivation.

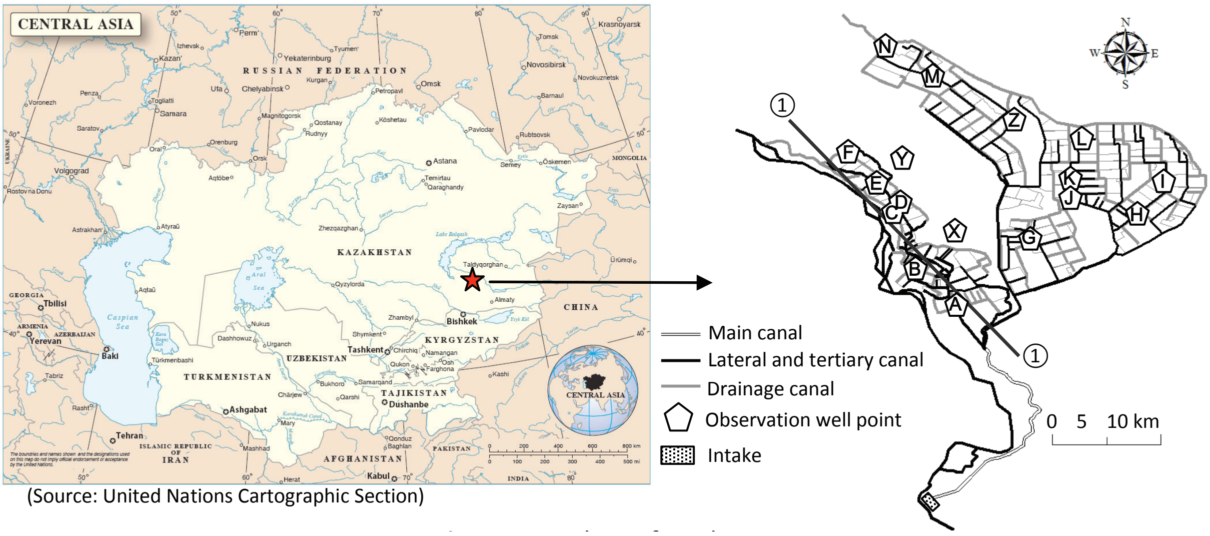
In the study area, the irrigation canals (main and branch canals) are unlined. Therefore, large amounts of water seep through into the ground. The design value of the conveyance efficiency is 0.75 and distribution efficiency is 0.60, the combined conveyance and distribution efficiency is estimated as 0.45 (Shimizu *et al.* 2010). Irrigation of fields is done only once or twice during early stage of growth. After that, continuous irrigation is practiced in rice fields while no irrigation water is givento other crops, which depend on the groundwater which is about 2 m under the surface because of seepage from canals and rice fields.

Data collection

Water withdrawal data from 1960 to1980’s was collected from annual reports on water use from archives. Data on withdrawal and crop planting after 1980’s was collected from annual reports on water use issued by Kazakhstan Water Resource Committee (WRC). Altitude and monthly groundwater level data was also collected from WRC.

Analysis methodology of groundwater level fluctuation

The study focused on fluctuation of groundwater level and clarified its characteristics by analyzing temporal and spatial fluctuation of groundwater level after development of the irrigation district. Temporal characteristics of groundwater level fluctuation were analyzed based on fluctuations of amount of withdrawal and irrigation rate. Spatial characteristics of groundwater level fluctuation were analyzed by comparing the characteristics of groundwater level fluctuation on each observation wells. The relationship of ground altitude and groundwater level was analyzed using altitude of observation wells and groundwater level data from the area.



(Source: United Nations Cartographic Section)

Figure1: Outline of study area.

Analysis methodology of condition of water supply to field

The influence of the seepage from canals and rice fields on groundwater level was investigated in fields during irrigation and non-irrigation periods. Figure 2 shows the position of observation points. Groundwater level observation and level survey was conducted at each observation points. From this investigation, the extent of the influence was revealed. Secondly, to calculate the ratio of fields covered by the extent of the influence, geographic information system (GIS) was used. Firstly, the field area covered by the extent of the influence and the ratio of this area to the area was calculated. Then, the area summed up with each ratio and finally the ratio of that summed up area to whole field area was calculated.

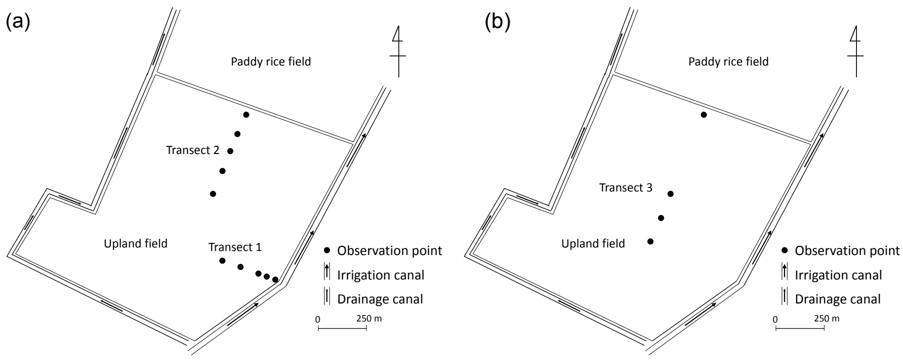


Figure 2: Spatial distribution of the field investigation of water table depth in (a) 2011 and (b) 2010.

Results and discussion

Temporal fluctuation of groundwater level

In lower Ili river basin, farmland development was carried out from 1967, and rice was officially introduced from the 1970's. Figure 3 shows relationship between groundwater depth (depth means distance from ground surface to groundwater surface) in August when there is peak irrigation and fluctuation of water withdrawal in Akdara irrigation district. From 1970's when rice cultivation started, large amount of water withdrawal was conducted. Groundwater depth was about 8 m on Well G before introduction of rice cultivation. Groundwater level raised sharply in the first half of 1970's after introduction of rice cultivation. After that, however, water withdrawal reached a maximum level of 1.2 billion m^3; currently the water withdrawal has decreased to 0.6 billion m^3. While groundwater depth was constant at about 1 m on Well I in 1980's, currently groundwater level is showing decreasing trend although there is fluctuation; furthermore this trend was observed on ten wells out of all seventeen wells. Recently, however, groundwater level is constant at 1.0~1.5 m. It might decrease with decrease in water withdrawal and upland crop might not be maintained under existing irrigation system.

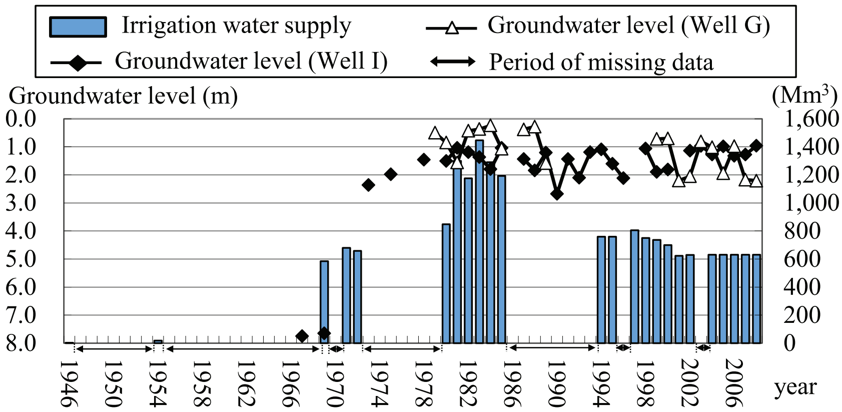


Figure 3: Fluctuation of groundwater level in August and amount of annual irrigation water supply.

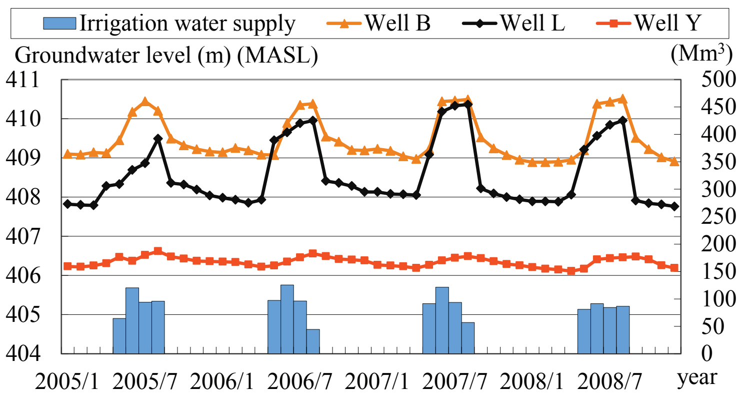


Figure 4: Fluctuation of groundwater level and water withdrawal.

Spatial fluctuation of groundwater level

Three wells were selected for this study. Figure 4 shows groundwater fluctuation from 2005 to 2008. On wells F and L, which are inside of the irrigation area, groundwater level rose sharply from May and groundwater level was highest in July and August. The level fell sharply from

September when irrigation stopped. After that it fell gently. While on well X, which is out of irrigation area, the highest groundwater level was in August and September. The peak of the groundwater level was delayed by one month compared with the wells inside the irrigation area.

Figure5 shows the altitude and average groundwater level at each point in January and August from 2005 to 2008 along the line (a) which draws from the upper to the lower part of the west branch canal. Groundwater level at each point is approximately parallel to altitude during non-irrigation period, but not during irrigation period. Therefore, the fluctuation of on each well was different. Figure 6 shows the fluctuation range on each well. The fluctuation in wells A to N, which are inside of the irrigation area, ranged from 1 m to 2 m, while in wells X,Y, and Z, which are outside of the irrigation area, it was about 0.5m.

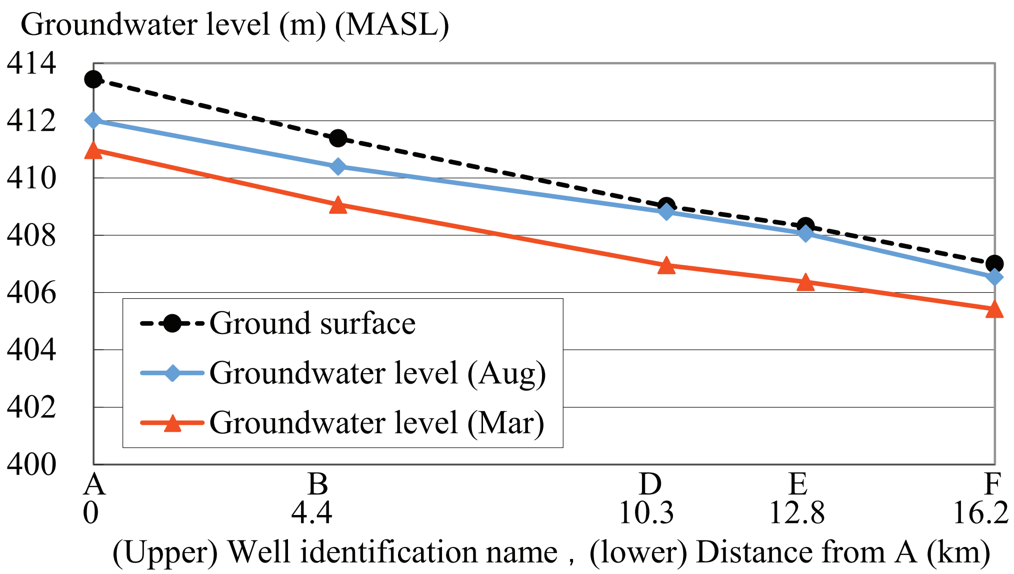


Figure 5: Inclinations of ground surface and average groundwater level along line.

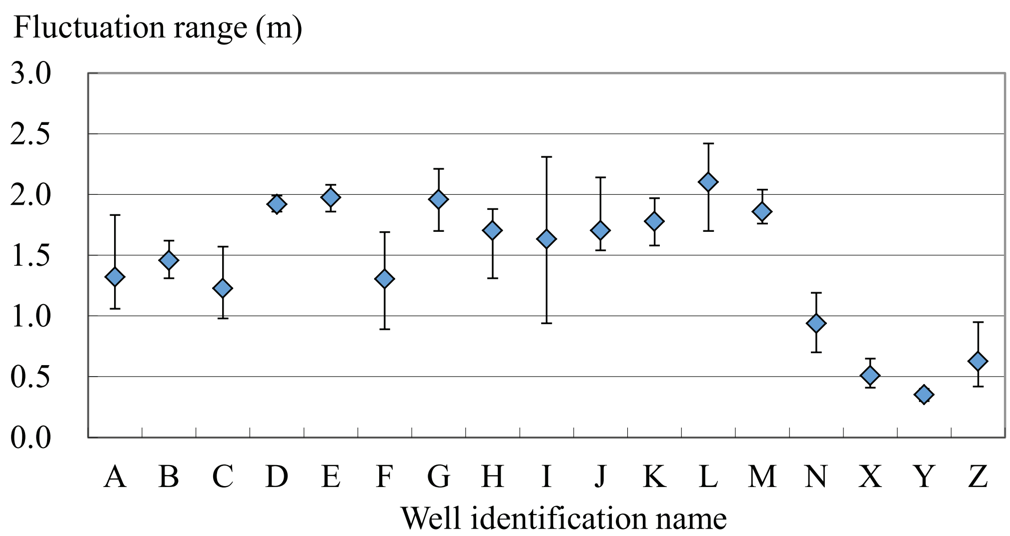


Figure 6: Relation between groundwater level and irrigation requirement for rice cropped field.

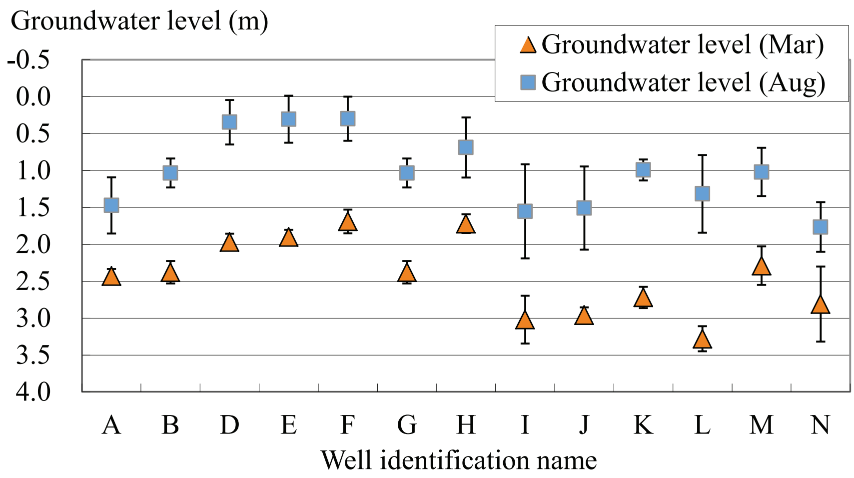


Figure 7: Average groundwater level on March and August at each Well.

Average groundwater level in March and August in each well is given in Figure7. The level in August was normally high in wells D, E, F, and H. It seems, irrigation raised the groundwater level excessively because of groundwater level in March was high rather than in other wells. In wells A, B, I, J, and L, which were close to rice fields exists, groundwater level was higher than where there were no rice fields. Groundwater level in August was not uniform at different locations. It appears that factors affecting groundwater level at each location are location specific.

Condition of water supply to fields

The relationship between the distance from canals and rice cropped fields and groundwater level was investigated in a field survey conducted in 2010 and 2011. Figure 8 shows the result of the influence of the seepage from canal. At the point close to the canal, groundwater level was about 3.5 m from ground surface in non-irrigation period, and about 1.5 m during irrigation period. Thus, the

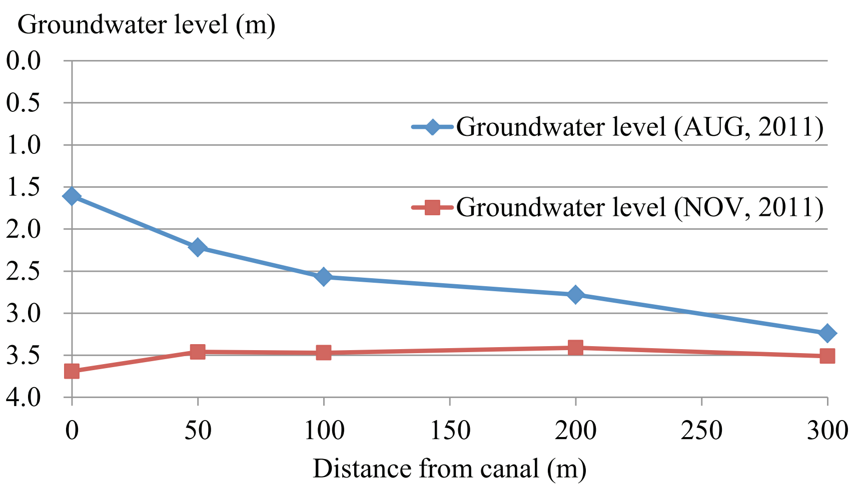


Figure 8: Relation between distance from canal and groundwater level.

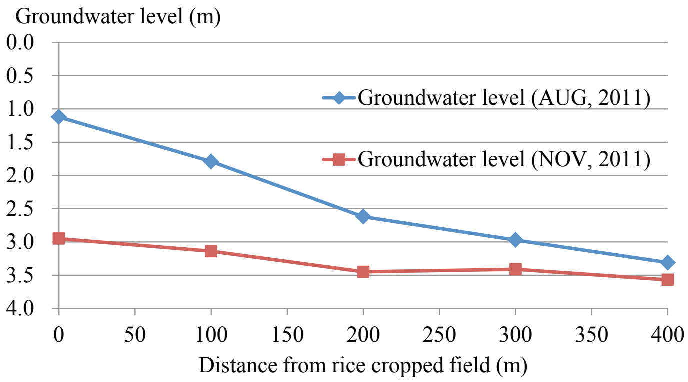


Figure 9: Relation between distance from rice cropped field and groundwater level.

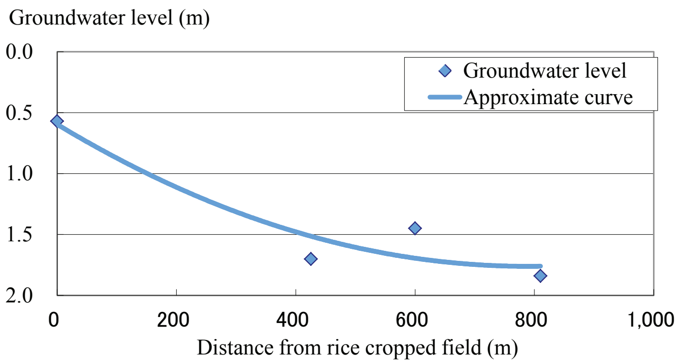


Figure 10: Relation between groundwater level and distance from rice cropped field

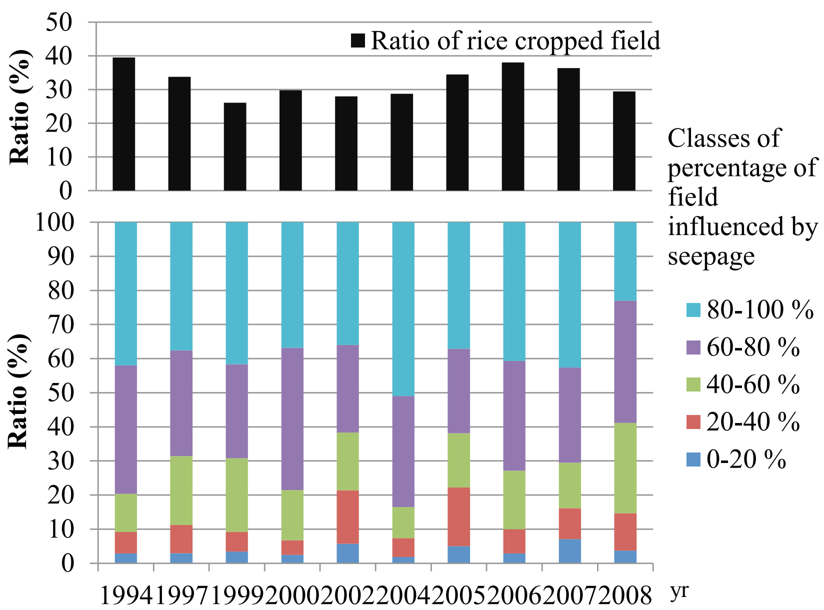


Figure11: Frequency of the proportion of field area influenced by seepage from canals and rice cropped fields and the proportion of the irrigation district under rice cropped field during the irrigation period for a sample of 10 irrigation seasons between 1994 and 2008.

groundwater level was raised by about 2.0 m by seepage from canal. During the irrigation period, groundwater level fell with increase in the distance from canal. At a distance of 300 m from the canal, groundwater level during irrigation period was almost equal to the level in non-irrigation period. In this area, the influence of seepage from canal in non-irrigation period was low.

Figure 9 shows the influence of the seepage from rice cropped fields. At the point near the rice field the groundwater level was about 3.0 m in non-irrigation period, and about 1.0 m in irrigation period, thus giving a rise of the level by about 2.0 m by seepage from rice field. In irrigation period, groundwater level fell with increase in the distance from rice cropped field. At 400 m outside the rice cropped field, the level in irrigation period was almost equal to the level in non-irrigation period. Thus here, the influence from rice cropped field was low. Figure 10 shows the influence of the seepage from rice cropped field analyzed during irrigation period in 2010. The water level fell sharply from the points close to the rice field to those about 500 m away. From this distance, the level fell gently. Thus, the influence of the seepage from canals and rice cropped field on groundwater level was apparent up to about 500 m.

As previously explained, about 500 m was considered as the extent of the influence of seepage on groundwater level of fields. This limit was applied to the irrigation district to clarify how much percentage of field area was covered by this influence. The graphic display about the influence of the seepage from canals and rice cropped field on groundwater level was done by using GIS to calculate the percentage.

Figure11 shows the ratio of area organized by ratio of field area covered by the extent of the influence and the ratio of rice cropped field area to whole area in each year. The field area where the ratio of the area which overlapped field area to whole field area was from 0 to 20 % was very low (maximum value is 7.07 % in 2007 and minimum value is 1.82 % in 2004). That is to say, the influence of the seepage is considered to reach whole fields in irrigation district. Recently, the ratio of rice fields has been maintained from about 30 % to 40%. The relationship between ratio of rice fields and ratio of fields covered by the extent of the influence was not observed. While the ratio of rice field in 2000 is almost the same as in 2008, each ratio of influence is not the same. From this result, it is apparent that the effect of the ratio of fields covered by the extent of the influence was not determined by area of rice cropped fields but by the position of rice cropped fields.

These results suggest that it is possible to supply water to fields under current irrigation system and the ratio of fields covered by the extent of the influence was affected by the position of rice cropped fields. In conclusion, the current irrigation system could be used to cultivate crops under the current water withdrawal system without practicing irrigation to fields. The position of rice cropped fields affected the ratio of fields covered by the extent of the influence of seepage.

Conclusions

As a first step towards the management of groundwater level, this study analyzed temporal and spatial distribution of groundwater level fluctuation. Additionally, the study analyzed the condition of water supply to field crops by seepage from canals and rice cropped fields. The results are summarized as follows;

1. While groundwater depth was about 8 m from ground surface before irrigation district developed, after 1970’s (when paddy rice cultivation started) groundwater level rose sharply up to about 2 m in four or five years.
2. While in 1980’s when water withdrawal was maximum, groundwater was at the highest level, recently water withdrawal has decreased and groundwater level is showing a decreasing trend.
3. Groundwater level rose sharply from May when irrigation started and the level was highest in July and August. It fell sharply from September when irrigation stopped. After that the level fell gently from October and November. This fluctuation was repeated every year.
4. While groundwater level at each point is approximately parallel to altitude during non-irrigation period, groundwater level of each point is not parallel to altitude during irrigation period. Range of groundwater level fluctuation was uniform.
5. Groundwater level in August was not uniform according to the location.
6. The condition of water supply to field crops was affected by the position of rice cropped field rather than by the area of rice cropped fields.

Recommendations

In order to protect water environment of Lake Balkhash, an approach to water resource management of Ili River Basin is required at the national level, irrigation district level and plot level. At the national level, Kazakhstan and China governments require global efforts to address consensus-building on sustainable water-use taking climate change into account. At the irrigation district level in Kazakhstan and China, water-saving approach is required to reduce amount of water withdrawal. Therefore, it is imperative not only to upgrade water facilities but also to evaluate the possibility of introducing effective water distribution. Finally at the plot level, farmland consolidation is required to reduce water losses. In addition, there is a need to estimate adequate amount of water requirement for each crop and each area, and develop rules to supply estimated amount of water for each plot. Finally to control groundwater level in fields adequately, it is necessary to supply different amount of water to rice field at each area based on its groundwater level. This approach might contribute not only to water-saving but also protecting soil salinization or water logging.

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Managing water resources under climatic change in the dry areas of North Africa and the Middle East

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Abstract

The dryland landscapes of North Africa and the Middle East are managed by cultivators and scientists who are skilled in identifying adaptation and mitigation strategies to maximize livelihood benefits, even under conditions of resource scarcity. Climatic changes have been increasing resource scarcity and variability in this region over several millennia. More recently, anthropogenic processes are further reducing resource availability and quality. Continuing climate changes are anticipated to exacerbate these effects. Following a brief description of the current situation and expected trends affecting the three main agroecosystems in the region, this paper reviews examples of promising and successful management strategies and ongoing scientific work on pilot testing these strategies by multidisciplinary teams from eight countries taking part in the USAID-funded Water and Livelihoods Initiative, led by ICARDA. The paper considers research progress and challenges to understand and predict cross-scale processes connecting water resource management on the ground to global climate change effects. Challenges for assessment of productivity and valuation of crops, livestock and ecosystem services in order to evaluate the costs and benefits of adaptation are also identified. The paper underlines the importance of connecting decision-makers' economic evaluations to continuous field level monitoring by cultivators and scientists.

Introduction

The International Panel for Climate Change's (IPCC) has predicted growing water scarcity effects across the Middle East and North Africa (Pachauri and Reisinger 2007; Verner and Breisinger 2012; Droogers *at al.* 2012). Areas that are already experiencing water stress are likely to experience additional declines in water availability for agriculture (WWAP 2012), leading to reduced agricultural yields (Medany 2008). These are anticipated to result in negative effects on rural incomes and food security (IBRD 2007, 2008, 2010; Breisinger *et al.* 2010). There have been various studies assessing the potential costs of climate change, and the needs for adaptation to manage water resources under increasing scarcity for agriculture and other sectors (Stern 2006; Eid *et al.* 2007,; Agrawala and Fankhauser 2008; EEAA 2010; Verner and Breisinger 2013).

Many of the available economic assessments of climate change and management options focus on the economic value of lost agricultural production (see practical guide for researchers in: Bolt *et al.* 2005, and accompanying case studies in Croitoru and Sarraf 2010). Assessments can be presented to decision-makers from the perspective of the rural household, or the national economy, or the global community (World Bank 2010**).** However, these economic assessments usually present only timebound snapshots of a dynamic situation using datasets that are at a coarse scale (e.g. national or governorate level). Generally, iterative field data collection and testing of potential adaptation options is not part of the economic assessment approach. Field level studies are usually conducted separately, and their findings do not often reach the target audiences of national decision-makers. The challenge to work across scales is recognized to be essential to addressing environmental changes (Pahl-Wostl 2009).

This paper reviews challenges encountered due to the effects of water scarcity and ongoing climatic changes in the three main agroecosystems which broadly characterize agricultural production in the region. The review draws on experiences generated through the Middle East and North Africa *Water and Livelihoods Initiative (WLI)*. This initiative is led by the International Center for Agricultural Research in the Dry Areas (ICARDA), with support from USAID, to enhance and apply science and technology to respond to the challenges of water scarcity, land degradation, water quality deterioration, food security and health problems within agricultural communities in Egypt, Iraq, Jordan, Lebanon, Libya, Syria, Tunisia, West Bank/Gaza and Yemen.

Essential scales of analysis identified through WLI include both farm household and national economic scales for the assessment of crop and livestock production value, as well as regional and global scales of climate trends and available models. In addition to these, the WLI works at basin scale for assessing water resource availability and use, and the field scale for assessing land and water management options. The WLI teams' achievements in developing decision-support tools and incorporating consideration of anticipated climatic changes may be of interest to other researchers in the region, and other areas facing challenges due to water scarcity and anticipated climatic changes. The intended outputs from WLI are relevant to national and regional agendas to achieve: 1) Integrated water and land-use strategies for policy-making, tools for sustainable benchmark management and organizational mechanisms for community inclusion at the benchmark sites. 2) Enhanced knowledge, skills and qualifications for key stakeholders in the benchmark sites. 3) Improved rural livelihoods of farmers in the benchmark sites through the adoption of sustainable land and water management practices and livelihood strategies.

Predicting impacts of climate change on regional agro-ecosystems

Expert assessments of water scarcity and climate change scenarios for agro-ecosystems were generated through the WLI coordination meetings and working group discussions 2012-13 (see: http://temp.icarda.org/wli/). These characterize the relationships between water resource availability, agricultural use, and dependent livelihoods in each agro-ecosystem (after Safriel *et al.* 2005), and identify promising strategies under research and pilot testing through WLI. In order to ensure effective adaptation to increasing water scarcity and climate change, these require continuous monitoring and periodic analysis at a range of critical scales.

Rangeland agro-ecosystems

Much of North Africa and the Middle East is rangeland. These are marginal dryland areas, where people are reliant on the environment to provide wild plants and animals as sources of food and other benefits for them and their livestock. Water may come from ephemeral rivers (wadis) or widely dispersed wells. Rangelands are often located in remote areas far from markets, where there are few economic opportunities, causing dependence and sometimes pressures on the environment. Mobility is often an important factor in rangeland livelihood strategies (Davies 2007). Animals are moved around, other food and water sometimes imported, periodic out-migration in search of economic opportunities is common and local alternative income generating opportunities include hosting of seasonal hunting, tourism, trade and hosting of visitors with interest in natural resource prospecting and land speculation. Balances between rainfall, vegetation, and dependent livestock and human populations are dynamic. In times of water scarcity, loss of vegetation and overgrazing can cause downward spirals of degradation that are difficult to reverse and rehabilitate.

Ensuring balance and creating synergies between people, animals and vegetation in the rangeland environment can involve harvesting of water, propagation of high value rangeland plant species, introduction of irrigated crops, product processing, including drying and curing of plant and animal products, honey, dairy and other foods products, other handicrafts, marketing, increasing mobility of people and livestock, and encouraging sustainable tourism, hunting and property development. Information on both ecological and economic productivity and diversity in the rangeland systems is often patchy. Agricultural extension and data collection to increase resilience in the rangelands requires work across wide geographical areas with societies that may traditionally be nomadic, bound by inherited land and water management rights, tribal family structures, and now undergoing difficult processes of social as well as climatic change (Chatty 2006). Economic assessment of land and water management adaptations can be achieved through rapid participatory work and/or ethnographic studies with rangeland societies to achieve resource management insights.

Rainfed agro-ecosystems

Rainfed agriculture takes place across much of the region, and is essential to sustainable food production (Rockstrım *et al.* 2010). Even where rainfall is quite scarce, rainfed production of cereals and fruits, e.g. wheat, barley and olives is practiced using traditional water harvesting techniques. Seasonal agricultural activities depend on rainfall collecting in wadi systems and spate irrigation systems. In some parts of the region, high value crops, e.g. coffee, almonds, peaches, figs and others are also produced under rainfed conditions for export. Local processing of these crops adds value and provides employment for rural households. Traditional systems for rainfed agricultural production and the conservation of soil and water are often labor intensive and require social organization. Where these systems cease to be economically viable, out-migration in search of alternative economic opportunities can cause them to decline. Climate changes and shocks can cause these systems to disintegrate and disappear altogether.

Increasing, restoring, updating, innovating and integrating the use of water harvesting and storage systems for agricultural and other uses is a key to reducing the vulnerability of the rainfed agro-ecosystems. Supplemental irrigation can increase resilience and is increasingly used as an adaptation strategy. Other key practices include conservation of soil and nutrients. Rainwater is often more available at higher elevations within a watershed. Conservation and use of water in areas of higher rainfall may affect the availability of surface and groundwater in other parts of a watershed. Information on total water balance in watersheds, use of water from non-renewable water and upstream-downstream tradeoffs in water management is often incomplete. Social organization is critical for ensuring watershed management and connecting it to the systematic generation and use of reliable statistics to generate effective assessments.

Table 1: Strategies and technologies reported by WLI teams under different stages of development

Agro-ecosystem	Under development		Field testing		Made available	
	Type	**No.**	**Type**	**No.**	**Type**	**No.**
Rangeland						
1. Jordan	Water spreading (Marab) for barley; contour ridge & Vllerani for shrubs	3	Cistern and ponds; Marab; contour ridge & Vallerani for shrubs	4	Marab; contour ridge &Vallerani for shrubs planting	3
2. Palestine		0	Drought resistant barley & wheat cvs.; fertilizer apln.; water harvesting (rock terracing); eye brow & contour ridges; semi-circle bund with grazing shrubs and contour-ridges for barley and wheat	8		-
Rain-fed						
1.Lebanon	IPM; drip irrigation	2	Conservation agri.; new grape variety; new cactus variety	0		3
2. Syria	Green manuring; deficit irrigation for sorghum and soybean); integrated. crop-animal production	4	Green manuring and fertigation	1	Green manuring	1
3. Yemen		0		0	Suppl. irrigation; crop mgt. for spate irrigation	2
Irrigated						
1.Egypt	Raised beds; - deficit irrigation	2	Raised bed; deficit irrigation; techniques for managing salt-affected soils	3	Sprinkler; drip irrigation; lining canals; buried pipes;-laser levelling; manure; composting; deep tilling; dry seeding clover; using certified cvs.; using gypsum; use of wheat seeders; rice machine transplanting	12
2. Iraq	deficit irrigation, surface and subsurface drip irrigation, improved greenhouse techniques, and using saline water to irrigate sun flowers					4

Irrigated agro-ecosystems

Irrigated agriculture is essential to regional food production, employment and income generation for rural livelihoods. Irrigated agro-ecosystems include large scale surface water distribution and drainage systems supported from large rivers, small scale systems dependent on groundwater, and a range of variations in between, often including conjunctive use of surface and groundwater (Thenkabail *et al.* 2009). While a slow shift to precision irrigation is taking place across the region, still the majority of irrigated lands are under flood irrigation. Water scarcity problems are particularly acute in reclamation areas, where soil is sandy, evapotranspiration rates are high, and rainfall is low, or non-existant. Climate change intensifies these problems. Water scarcity is often combined with water quality and salinity management challenges that are unevenly distributed across large scale systems. Tail ends of irrigation canals often do not receive sufficient water supplies, and can resort to reuse of poor quality drainage water or increased groundwater use. In groundwater-dependent areas, falling groundwater tables and rising pumping costs further exacerbate water scarcity problems.

Traditional water conservation practices include soil improvement using raised beds, composting, mulching and manure from livestock, and reduction of evapotranspiration through use of shelter-belts and intercropping. Deficit irrigation can further increase water use efficiency and productivity, even under increasing scarcity. Where sprinkler, drip or hydroponic systems are in use, farmers have more control over the volumes, timing and content of irrigation water applications. In order to perfect the use of deficit irrigation scheduling, it is necessary to understand seasonal evapotranspiration rates and plant-water requirements, which can be affected by climate changes in various ways, including effects on growth stages, pollination, pests, and nutrient needs. Use of these techniques in areas where water supplies are of marginal quality and land is already salt-affected introduces additional challenges that require careful balancing of management practices and selection of well-adapted crops. Resource management and data collection, including both water management data and economic data, require work with commercial resource users in the private sector.

Assessing progress in response to increasing water scarcity and climate change

Assessing water availability and agricultural use across spatial scales

In the case of larger basins in the Middle East and North Africa, such as the Nile and Tigris Euphrates, basin scale assessments balancing future scenarios for supply and demand of water have been developed to support national decision-making. The Water Evaluation and Planning (WEAP) model (SEI 2005) provides a useful framework through which to review available water balance assessments and create new ones for basins where such assessments are not yet available. WEAP focuses on assessment of the balance between supply sources (e.g. rainfall, rivers, groundwater, and reservoirs); and demands for withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. WEAP can be readily combined with distributed hydrological and climate models (Droogers *et al.* 2012; Hadded *et al.* 2013) and will accommodate the effects of withdrawals for non-agricultural uses, which are considered likely to increase in the selected study areas.

Falling water tables (resulting both directly from climate change, and from adaptations requiring increased groundwater use) are already being observed in many parts of the region. An exchange student from UI-UC has expressed some interest in connecting SWAT to downscaled climate models and available data on groundwater conditions. This could work will within the WEAP framework (see e.g. Hadded *et al.* 2013).

The WLI team is already developing two PhD studies connecting available Syrian national water resource assessments and climate data to basin-oriented decision support using WEAP. In the Lebanese part of the basin at El Qaa, WLI researchers are monitoring water availability and distribution to the irrigation system, and preparing GIS maps to enable calculation of agricultural water use volumes. At the Majdiyyeh Benchmark Site in Jordan, the research team is working on the assumption that 100% of rainfall becomes runoff and is wasted unless it can be harvested. They are using the Soil and Water Assessment Tool (SWAT, http://swat.tamu.edu/) to investigate this assumption and identify impacts on evapotranspiration and crop production. Further use of SWAT to model water availability and use has begun in Palestine and has been proposed to improve watershed management in Yemen during 2013. At the WLI site in Southern Tunisia, SWAT has previously been used to quantify volumes of average annual rainfall (209 mm) used in evapotranspiration (green water), groundwater recharge and outflow (blue water) *(*Ouessar *et al.* 2009).

To complete the WEAP water balance calculations, estimates of demands for withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation are needed. The WLI Tunisia team has proposed to use analyses of NDVI and canopy senescence to identify agricultural water extraction and use, based on the extent of cropped areas, evapotranspiration, water stress, salinization effects, and other information concerning productivity in some crops (Allen *et al.* 1998). This will help to evaluate the water balance under current management practices and future scenarios (after Jasrotia et al. 2009). Various future land use scenarios have already been explored by WLI teams in Iraq and Yemen, generating land suitability maps that could also be used to project agricultural water demand scenarios. Estimating withdrawals and water uses associated with other sectors is often more of a challenge for agricultural water and land managers who may not have access to complete data (INWEH 2010). However, wherever estimates can be generated, this may lead to review and refinement. Hopefully, the PhD studies in the Orontes basin and elsewhere will help with this.

Land and water management options to manage climate change

Integrated land and water management, including groundwater recharge, retention, reuse and rainwater storage, is essential to climate adaptation and development (Van Steenbergen *et al.* 2009). All WLI teams are already active in developing and pilot testing integrated water, land-use and livelihoods strategies in the benchmark sites. These strategies involve field testing, adaptation and monitoring effects of water harvesting, micro-climate regulation, irrigation management, and using saline water on crop and livestock productivity. By the end of 2012, over 40 technologies were under different phases of development **(Table 1).** The total area under improved technologies amounted to 1677 hectares.

The WLI Tunisia team has identified a typology of land and water management strategies and technologies that are particularly relevant for adaptation to anticipated climatic changes, and reviewed previous studies focusing on the assessment of three main types of technologies: 1) Water harvesting to use available water, while reducing water losses, erosion and flood damage; 2) Cropping patterns that reduce evapotranspiration (alley cropping to create favorable microclimate); and 3) Watering strategies for crops and livestock (including supplemental irrigation, deficit irrigation and increased use of marginal quality water for crops and livestock).

Previous work on the assessment of **water harvesting** structures as an adaptation to climate change by the WLI Tunisia team members has combined scenarios from the HadCM3 model with Google Earth to map known soil characteristics and sediments captured by water harvesting (Sghaier *et al.* 2011). A simple water budget model then identified the depth of soil necessary to retain sufficient water for olive production (Raes 2002). This enabled projections for losses of olive production where soil depth would not be sufficient to ensure resilience to climate change. Other studies have used SWAT to evaluate the effects of water harvesting structures on evapotranspiration for crop production, recharge and outflow from the water harvesting area (Ouessar *et al.* 2009, Tubeileh 2009). Work using SWAT to evaluate water harvesting interventions in Jordan and Palestine is ongoing through WLI.

Adapting cropping, grazing and livestock production patterns to increase resilience to climate change includes introduction of drought resistant species, and adoption of cropping patterns that reduce evapotranspiration by sheltering plants from wind and sun. Planting drought resistant trees and shrubs and adapting grazing strategies is an essential part of strategies for rehabilitation of rangelands in Jordan, Palestine and Tunisia. These then enable soil improvement and a succession of more sensitive species to be reestablished. In the rainfed and irrigated areas, use of canopies created by fruit trees and/or cactus provides shade to cultivate vegetable and barley crops. Intercropping of cactus and barley has also been demonstrated as a promising strategy (Alary *et al.* 2007). The presence of cactus creates a microclimate around itself which enhances water retention in the soil, and increases soil fertility. This can increase the productivity of the barley, translating into improved livestock nutrition.

Similarly, in the irrigated systems, tree crops have been found by WLI research teams to contribute to enhancing resilience at tail ends of irrigation canals. Intercropping options are common in irrigation systems, particularly the traditional oases. There is plenty of literature and models on the oasis effect and reduced evapotranspiration (Saaroni *et al.* 2004, Potchter *et al.* 2008). Some basic tools for modeling crop water requirements in intercropping systems do exist (e.g. CropWat 8.0) through which the reduction of evapotranspiration and water requirements in intercropping of fruit trees and ground crops can be modeled.

Adaptation of watering strategies includes consideration of the potential for use of water from sources that are marginal – e.g. saline drainage waters or groundwater. These strategies may involve requirements for investment in infrastructure for water delivery to crops, livestock and rural households, and drainage systems to remove or redirect wastewater supplies. Ensuring correct timing and volume of water delivery can reduce over-irrigation and waste of water. In traditional large scale irrigation systems, where water delivery is periodic, there are challenges to reduce system losses and ensure effective timing of the rotation. In smaller or more modern irrigation systems, where there is continual access to water, precision delivery of water according to plant needs can support effective use of supplemental and deficit irrigation techniques using sprinkler, surface or sub-surface drip or hydroponic systems. Additional technologies, e.g. remote sensing, soil water sensors, infra-red thermometers can help to detect water stress (Er-Raki *et al.* 2008).

The WLI teams in Iraq, Lebanon and Syria, and elsewhere have experimented with regulation of irrigation water application using surface and subsurface drip irrigation systems, and succeeded to identify opportunities for reduced water application without loss of production. Water savings identified through experimentation by the WLI research teams with the introduction of deficit irrigation during 2012 included e.g. up to 60% reduction in irrigation water requirements without negative effects on productivity of eggplant.

Assessing, monitoring and valuing productivity scenarios

To assess management scenarios, including available adaptation options, decision-makers need economic valuations through which alternative management options can be compared. In their work to identify livelihood improvements that result from improved land and water management strategies, the WLI teams have identified the basis for economic assessments focusing at the farm level, and are continuing work to improve their use of socio-economic surveys. A number of challenges remain in this work, which require attention in order for them to be able to predict the economic effects of their strategies to improve the management of water scarcity, climate change, on-farm productivity and rural livelihoods. This may involve further integration of socio-economic survey instruments (drawing on recommendations in Bandyopadhyay *et al.* 2011; McCarthy 2011), together with other on-farm data collection and analysis (Stocking and Murnaghan 2001).

Climate change impacts on productivity of crops

WLI research teams have been studying the production of dominant crops grown in their agro-ecosystems, under the various pilot tested land and water management strategies. Challenges include the difficulty to capture and characterize the diversity of crops and crop combinations grown by farmers in this region. Nevertheless, the research teams have already been able to prioritize assessments of the major crops in their study areas and identify gross margins per hectare of on-farm income that are generated from a number of them. A list of remaining high priority farm budgets associated with cropping patterns and management strategies that appear promising to enhance the management of scarce water resources in the region has been developed, and will be the focus of further study during the coming year (Table 2).

For selected crops, crop-productivity models increasingly used to predict impacts of climate change on crop production include CropSyst, DSSAT or APSIM, generic models like EPIC, or the Agricultural Model Inter-comparison and Improvement Project (AGMIP) (http://www.agmip.org/), which aims to overcome the "single model" approach. For some crops, such as wheat, decision-support models (i.e. Aquacrop) are readily available. For others, such as olives, citrus and peach, fewer models to predict water requirements and productivity are available.

Where there is no suitable model available, it is necessary to calculate the crop-water productivity relation based on the available equations. A draft listing of best available models of crop water requirements and responses to water stress in use by the WLI Tunisia team has been compiled (Table 3).

Table 2: Dominant crops by agro-ecosystem: WLI progress in observation of on-farm income

Agro-ecosystem	Country	Budgets observed 2012	Remaining priority to address in 2013
Rangeland	Jordan	Wheat, barley	Livestock
	Palestine	Wheat, barley	Livestock
Rain-fed	Tunisia	(NA)	Barley, livestock, cactus, olive, citrus, vegetables
	Lebanon	Vegetables, cactus	Soft fruit, including peach, grape, apricot, apple, nectarine
	Syria		Cotton, sorghum, soybean, anise
	Yemen	Cotton	Sesame, lipids, livestock
Irrigated	Egypt	Wheat, rice	Sugar beet, fruit trees, livestock
	Iraq	Tomato, eggplant	Wheat, , fodder, livestock

Table 3: Available models to capture climate effects on productivity (at WLI Tunisia inception)

Cropping Systems	Model	Required Model Outputs to Impacts of Different Climate Change Scenarios
Rangeland-Olive- small scale irrigation	Budget (Raes *et al.* 2002) SWAT	• Olive yield (ton/ha/yr) • Potato yield (ton/ha/yr) • Extent of cultivable areas (ha olive and irrigated veg) • Water consumption at watershed level (Mm^3/yr) • Water Use Efficiency (crop yield/m^3 water)
Barley/livestock	Alary and Nefzaoui / Aquacrop/ RothC	• Feed yields (kg/ha/yr barley and cactus) • Water yield for watering of livestock (water consumed directly or from cactus) • meat production (kg/ha/yr) • veg. yield (ton/ha/yr) • WUE (kg meat/m^3 water incl. rainfall and irrigation) • extent of cultivable area (ha of main cropping systems) • Water consumption at watershed level (Mm^3/yr) • Soil water retention and SOC
Rainfed wheat	Aquacrop	• wheat yield (ton/ha/yr) • citrus yield (ton/ha/yr) • RUE (crop yield/m^3 rainwater water) • WUE (crop yield/m^3 water) • runoff/blue water • Extent of cultivable areas (ha wheat and citrus) • Water consumption at watershed level (Mm^3/yr)
Irrigated citrus	CropWat 8.0	

In addition to considering crops that are dominant at present, it is also important to consider crops that are better adapted to water scarce or saline production conditions, since future market conditions are difficult to predict, but increasing water scarcity and salinity are already being predicted with a fair degree of certainty to result from ongoing climate changes.

Integration of climate change impacts on livestock production for household income

Livestock are central to economic production in the rangelands, but also important for households in the rainfed and irrigated agro-ecosystems. Economic assessment of the impacts of climate and adaptation strategies on livestock productivity involves a particularly challenging chain of estimates and assumptions needed to relate production of natural vegetation, feed and watering strategies, meat and dairy production and marketing to obtain the required valuation. As a general estimate, 8kg of dry matter may be considered to support the production of an additional 1kg of meat (Awawdeh 2013). This practical estimate has been adopted by the WLI research team in Jordan. The WLI Tunisia team has proposed a more detailed investigation of livestock responses to feed and watering strategies under increasing water scarcity and climate change.

Other ecosystem services or externalities of IWLM

Valuation of the effects of integrated land and water management on ecosystem services other than crop and livestock production is an important element in the total economic valuation of climate change scenarios (Brink 2011). There is general agreement amongst the international scientific community that work on the identification and valuation of ecosystem services is needed (see introductory guide in: Tomich *et al.* 2010). The WLI Tunisia team has proposed to use the emerging research methods in this field to explore benefits for the society that can be achieved, when local- and national-scale externalities of IWLM, such as increased soil fertility and water holding capacity are taken into consideration. They also plan to consider global-scale externalities, such as biodiversity protection and carbon sequestration (after Campos *et al.* 2007; Daly-Hassen *et al.* 2010; Croitoru and Daly-Hassen 2010; Gracia *et al.* 2011).

Conclusions

Considerable progress has been made by WLI research teams towards understanding and predicting cross-scale processes connecting water resource management on the ground to global climate change effects. Decision-makers need to know what will be the economic losses due to climate change, what options are available for adaptation through IWLM, and what will be the costs and benefits of each strategy. The WLI teams have generated the necessary evidence base for IWLM options to be effectively presented to decision-makers as a means to manage increasing water scarcity and climate change in North Africa and the Middle East.

Key scientific challenges and research needs in order to evaluate the costs and benefits of adaptations involving different agricultural land and water management strategies remain. These include challenges to assess, model and value crop and livestock production for a diversity of dominant and better adapted crops and livestock and improve the integration of socio-economic survey instruments together with other on-farm data collection and analysis. There is also a need for more comprehensive assessment models and modeling approaches to capture effects on a wider range of ecosystem services.

WLI has more work to do in order to integrate its iterative field data collection and testing of potential adaptation options with the generation of outputs that could reach the target audiences of national decision-makers. This integration will not only add value to the field level studies, but could also ensure more practical systems to be put in place across the region for continual monitoring reevaluation and improvement of resource management policies.

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Effects of irrigation frequency on yield and quality of melon under open field conditions in Minqin oasis

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Abstract

A better understanding of the effects of irrigation frequency on production and quality of melon (*Cucumis melo cv.* Huanghemi) plants can help to propose optimal irrigation scheduling. For this purpose, experiments were conducted to determine the most suitable irrigation frequencies in melon grown in field conditions under furrow irrigation in the Minqin oasis, northwest China. Three irrigation intervals (15 , 10 and 7 days, T1,T2 and T3, respectively) were tested in the study. Plants were adequately watered from sowing to final thinning stage with the same irrigation frequency, and then were irrigated at 15, 10 and 7 days intervals, depending on the treatment. The total water applied was equal for all the treatments. The results showed that higher the irrigation frequency, the higher was the biomass, fresh weight of the single melon, leaves and stem, TSS, total sugar and total amino acids. However, the firmness of fruit decreased with increase in the frequency of irrigation. Although the yield under T3 was the highest (27.8 t ha^{-1}) and that of T1was the lowest (19.06 t ha^{-1}), the market value of T2 and T3 was significantly higher than that of T1 and there was no obvious difference between T2 and T3. The study indicates that the T2 (10 days) is the best irrigation interval for melon (*Cucumis melo cv.* Huanghemi) in the Minqin oasis.

Introduction

Agriculture is the largest single user of water with 65-75% of freshwater being currently used for irrigation (Bennett 2000; Prathapar 2000). In some cases, it draws as much as 90% of the total water (Allan 1997). It is necessary to get maximum yield in agriculture by using available water in order to get maximum profit per unit area because there is continuous decrease in agricultural land and irrigation water. In many arid regions the only water available to the farmers is the saline groundwater. Saline water is not beneficial to irrigated agriculture, but it may still be the major irrigation water source in extensive arid regions, especially in developing countries where extreme shortage of freshwater and the rapidly increasing population require more water (Huang *et al.* 2011). Drought and salinization are two main factors affecting the arid irrigated agriculture (Tedeschi *et al.* 2007). The long-term uses of the salinized groundwater combined with a high evaporation demand of the area have promoted soil salinization. Soil salinization results in the drying out of vegetation, desertification, and environmental degradation. The negative impact of saline irrigation water can be mitigated by implementing appropriate management of saline water and irrigation schedule for the plants (Ahmet *et al*. 2004).

Over-exploitation and severe wastage of water resources have long been a serious problem in the arid northwest China and have resulted in a series of adverse effects on the hydrogeological regime and terrestrial ecology (Ma *et al.* 2005; Feng *et al.* 2004). This area is an ecologically fragile area, which is characterized by low and irregular rainfall, high temperatures, strong evaporation and notable drought periods. The surface water and ground water in this region only account for 3.3% and 5.5%, respectively of the national total, whilst the area occupies 24.5% of Chinese total landmass (Shi and Zhang 1995). The total water resource shortage in arid northwest China has severe implications for water supply both for drinking and irrigation in the region (Li *et al.* 2004).

Irrigation in arid and semi-arid regions of China poses serious problems of soil salinization and land degradation caused by this problem has adversely affected field productivity. To get the desired profit from irrigation, time, length, and quantity of irrigation should be usefully determined. Scheduling water application is very critical to make the most efficient use of limited water resources, as excessive irrigation leads to high water losses and low irrigation efficiencies, while inadequate irrigation causes water stress and reduces production. Yield increase in intensive farming practices mostly depends on timely and adequate application of irrigation water needed for plant growth (Kenan *et al.* 2007). It is expected that good management and adoption of suitable practices will improve the water conservation and result in more efficient crop production under both rain fed and irrigated conditions (Wang and Tian 2004). Therefore, it is important to determine the right irrigation frequency for plants during the vegetation period (Kenan *et al.* 2007).

This study was carried out under field conditions on the *Cucumis melo* cv. Huanghemi, an important cash crop cultivated in the Minqin Oasis, with the objective of evaluating the effect of three irrigation frequencies on yield, total biomass, fresh weight of the single melon, leaves and stem, as well as melon TSS and firmness. A better understanding of the effects of irrigation frequency on the above parameters could help to develop optimal irrigation strategies.

Materials and methods

Study area

The study was carried out in the Minqin oasis, which is located in the lower reach of the Shiyang River (Shi and Zhang 1995). The Minqin oasis is approximately between latitudes 3820′° to 3918′° North and longitudes 10252′° to 10350′° East. It is surrounded by Badai Jaran Desert on the northwest and Tengger Desert on the north and east sides, while the WuWei basin is to the south (Figure 1). Minqin oasis is a region with a fragile ecosystem and a severe shortage of water resources . The annual precipitation is about 113 mm, and almost 74% of it is recorded in June to September. Evaporation is very strong and the mean annual evaporation can reach 2640 mm. The mean annual temperature is around 7.7 °C and the mean annual wind speed is 2.8 m s^{-1}, the highest wind speed can reach 23 m s^{-1}, and the main wind direction is northwest (Chang *et al*. 2002). Average air humidity is 49% and aridity is 5.3 (Zhao *et al.* 2003).

The over use of surface water and ground water in the upper and middle reach of Shiyang river has resulted in the rapid reduction of water flow into the lower reach, Minqin oasis. Since 1940s, the rapid increase of population in Minqin oasis has led to an increase of irrigated farmlands mainly by conversion of grassland has been reclaimed and became farmlands. The increase of farmland combined with traditional flood irrigation increased the use of water resource. In Minqin oasis, 85% water supply comes mainly from groundwater, (Chang and Zhao 2006). The water table of Minqin Desert Control Station and the surrounding area was 1-3 m in 1950s and by the end of 2004 it reached 16.4-22.2 m. Exploitation of groundwater in Minqin was less then 1.0×108 m^3 before 1970s and it received 5.84×۱۰۸ m^3 in 2005, an increase of 0.2×108 m^3 every year (GSWRB 2007). In Minqin oasis, almost every index of water exceeds the National Standards for Groundwater Quality. Hongyashan reservoir is in the south and groundwater can be recharged by reservoir water, so the ground water there has a better quality than that in other parts of the basin. In the north, adjacent to the Tenggri desert, the groundwater quality is the worst because of lack of surface water recharge and overuse of groundwater; the total dissolved solids (TDS) of well water along the desert margin can reach 10 g L^{-1}(GSWRB 2007). As a result of irrigation with alkali-saline ground water, soil salinization has increased significantly in recent decades in the Minqin oasis (Ma and Wei 2003; Feng *et al.* 1997).

Experimental site

This study was conducted in a farmer's field located in the northeast margin of Minqin oasis, just nearby Tengger desert (Figure 1). The land was flat and soil silt loam. Some physical and chemical properties of the soil of the experimental are given in the Table 1.

Table1: The texture, bulk density and $EC_{(1:5)}$ of soil in the experimental site

Depth cm	**Soil texture**			**Soil bulk density $g \cdot cm^{-3}$**	**$EC_{(1:5)}^{*}$ $mS\ cm^{-1}$**
	clay %	**silt %**	**sand %**		
0-30	16.8	46.4	36.8	1.54	0.89
30-60	20.2	59.2	20.6	1.57	1.53
60-100	14.8	54.5	30.7	1.46	1.46

*Electrical conductivity of liquid of solution in which 10g of soil is mixed with 50ml water.

The experiment was set out as a randomized block design, with a split plot treatment arrangement. Three irrigation treatments were applied to the whole plots: furrow irrigation at 15, 10 and 7 days intervals (coded as T1, T2 and T3, respectively). Melon (*Cucumis melo* cv. Huanghemi) is an important cash crop cultivated in Minqin oasis. Melon was sown in a double-row bed, the distance between the twin rows was 1.0 m, the distance across the double row bed was 0.70 m, and plants along a row were spaced 0.44 m apart. Experimental plots consisted of 10 rows each 9.0 m long. Plants were adequately watered from seed sowing to final thinning with the same irrigation frequency, and then irrigated at 15, 10 and 7 days intervals as per the reatment. The total water applied in the growing season (148 mm) was equal for all treatments. A total of was applied in the growing season. Saline irrigation water (8g L^{-1}) was applied to each furrow in each plot uniformly using a water meter. The treatment program was stopped at the end of September. The water used for irrigation was obtained from a deep well in the experimental area. The furrows and part of the ridge were covered by 0.1 mm thick white low-density polyethylene film (LDPE). On the ridge a central strip of soil about 0.30 m wide was left uncovered. Along the bottom of the furrows some holes in the LDPE film were made to facilitate water infiltration and movement.

Plant sampling

Total biomass, fresh and dry weight of leaves, stem and root were measured biweekly in the growing season. The fruits were harvested at the optimum ripening stage. Time to harvest was recorded as number of days after thinning (DAT) and occurrence of the different phenological growth stages and harvesting time were recorded. The number of fruit and the weight of each fruit were determined to evaluate mean fruit weight. Ten plants were selected from each treatment at the harvest period to measure yield, total biomass, fresh and dry weight of the single melon, fresh and dry weight of leaves and stem, as well as of melon TSS and firmness. Plant samples were put in oven at 65°C after taking fresh weight until they reached constant weight, to determine dry weight. The fruits were split with a knife along the equatorial diameter to measure flesh hardness with a penetrometer (Fruit Pressure Tester FT-327) in the middle of the flesh. Total soluble solid (TSS) content was measured with a digital refractometer (Atago) and expressed as °Brix. Extracted juice from the fruit was placed in small bottles and immediately frozen at -20 °C for further analysis. The juice was used to analyze the total sugar. The defatted samples were hydrolyzed in 10 mL 6 M HCl at 110 °C for 24 h under constant flowing nitrogen. The cooled and filtered hydrolyzate was then dried in a vacuum desiccator at 45 °C and re-dissolved in citrate buffer (pH 2.2). Aliquots of the solution were injected directly into a Sycom S-433 D automatic amino acid analyzer (Sykam, Eresing, Germany) to determine amino acids content (Zong *et al.* 2011).

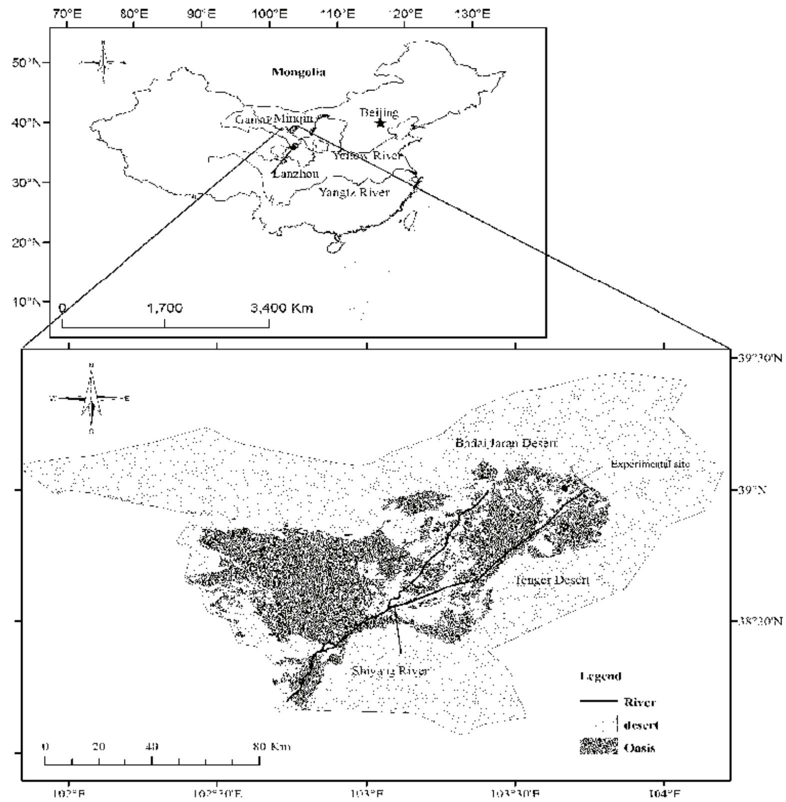

Figure 1: Location of the study area.

Results and discussion

Biomass, leave and stem weights

Biomass, leaves and stem fresh weights data for single plant are summarized in the Figure 2. The irrigation frequency significantly affected melon yield. The biomass increased with the increasing irrigation frequency both at DAT30 and DAT60. The biomass of T1 was less than that of T2 and T3 significantly (Duncan's test, $P \leq 0.05$) but there was no obvious difference between T2 and T3. Katsoulas *et al.* (2006) showed that both treatments followed almost the same trend during the period of measurements for roses grown for cut flowers. The leaves and stem fresh weights had the same trend.

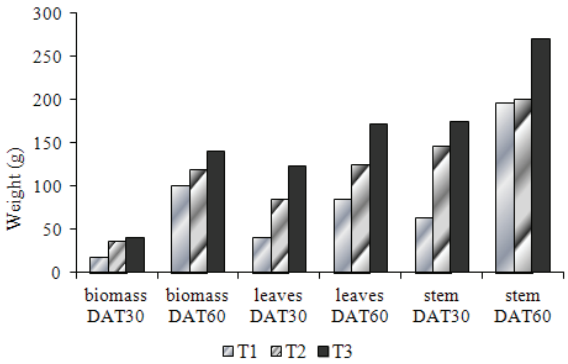

Figure 2: Biomass (dry weight), leaves and stems fresh weight of different treatments. Interaction treatments (T1:15 days; T2: 10 days; T3: 7 days) × time (days after thinning, DAT).

Melon yield and marketable rate

With the increase of irrigation frequency the melon yield increased (Figure 3). The yield of T2 and T3 was significantly higher than that of T1, but there was no significantly difference between T2 and T3 ($P \leq 0.05$). Suat et al. (2007) showed that irrigation frequency plays significant role in fruit yield of melon grown in field conditions. Wang et al. (2011) demonstrated the same for potato tuber yield. Kang et al. (2004) and Wang et al. (2006) also reported the same.

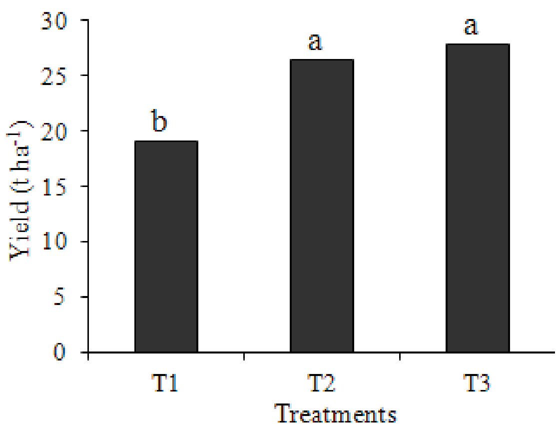

Figure 3: Yield of different treatments (T1:15 days; T2: 10 days; T3: 7 days). Values followed by the same letter are not significantly different at $P \leq 0.05$.

The fruit size (weight) is an important determinant of market value. Hence all the fruits harvested were divided into the five size classes shown in Table 2. In treatment T1, 15.2% of the product was in the Class I and most fruits were in Class II and Class III (small and small to medium size). In T2 most fruits belong to small-medium size; while in T3 most belonged to small-medium, medium-large, and large size; especially large size fruits (Class V) in T3 was higher than in T1 and T2. Of all the treatments, the T1 resulted in the smallest size fruit and T3 resulted in the largest size fruit. Suat *et al.* (2007) showed that more frequent irrigation resulted in greater number of marketable fruits.

Table 2: Class size division of the marketable fruit expressed as % of total weight: saline treatment ×fsize class interaction. Values followed by the same letter are not significantly different at P ≤ 0.05.

Marketable fruit divided into classes	**Unit**	**Treatments**		
		T1	**T2**	**T3**
Class I: No market value <500g	%	15.2d	0.1e	1.1e
Class II: small size 500-1000g	%	29.1bcd	35.0bc	21.1d
Class III: small-medium size 1000-1500g	%	35.5bc	47.5a	38.9ab
Class IV: medium-large size 1500-2000g	%	17.7d	16.4d	27.8cd
Class V: large size >2000g	%	2.5e	1.0e	11.1de

Irrigation at different frequencies produced a significant difference in mean fruit weight (Figure 4). The mean fruit weight increased with the increase in irrigation frequency. The mean single melon weight of T3 was significantly (P test, antler than that of T1 and T2 but there was no significant difference between T1 and T2. The number of fruits per plant produced also increased with the increase in irrigation frequency. The mean number of fruit per plant produced of T1, T2 and T3 is 0.95, 0.98 and 1.02 respectively. In other words, both the mean single melon weight and the mean number of fruit per plant produced are increasing with the increase irrigation frequency, accordingly the yield and fruit market value are increasing with the increase irrigation frequency.

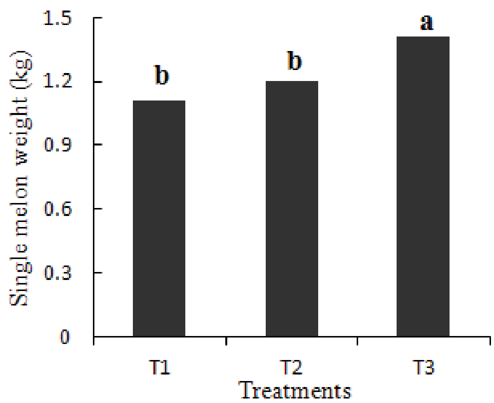

Figure 4: Single melon weight of different treatments (T1:15 days; T2: 10 days; T3: 7 days). Values followed by the same letter are not significantly different at P ≤0.05.

Melon quality

Some quality parameters of melon are given in the Table 3. All the quality parameters in the table were affected by irrigation frequency significantly (P test). The firmness under T1 was significantly higher than that under T2 and T3, which showed no significant differences amongst them. TSS, total sugar and total amino acids also increased with the increase in irrigation frequency, T1 being significantly inferior to T2 and T3. Differences between T2 and T3 were not significant. Frequent irrigation created a more humid soil environmental condition which favored nutrient uptake by melon roots. Similar results were found in the works by Zhou *et al.* (2004) and Wang *et al.* (2011).

Table 3: Effect of irrigation frequency on some quality parameters of melon. Values followed by the same letter are not significantly different at $P \leq 0.05$.

Treatments	Firmness	TSS (°Brix)	Total sugar (g kg^{-1})	Sum of amino acids (mg $100mL^{-1}$)
T1	3.54a	10.7b	99.2b	421.37b
T2	2.39b	14.45a	112.3a	622.25a
T3	2.92b	16.94a	122.8a	652.13a

Conclusions

Melon is commonly grown as a dry land cash crop in Minqin oasis, but it responds significantly to irrigation. This study demonstrated that irrigation frequency is important in determining the yield and market value of melon. With increasing irrigation frequency the biomass, yield, market value, weight of the single melon, leaves and stem, TSS, total sugar and total amino acids increased, but the firmness decreased. Based on the comprehensive analyses of all the parameters, the study indicates that irrigation at 10 days interval was the best treatment for melon (*Cucumis melo cv* Huanghemi) in the Minqin oasis.

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Seasonal water uptake for halophytic shrubs in northwest China salinity-affected area: an isotopic investigation

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Abstract

Shallow groundwater table is the main cause of salinization in the northern area of Ningxia Plain. The uptake of groundwater by halophytes can control groundwater table. Potential water sources of four halophytic shrubs, i.e. twenty-year-old *Tamarix ramosissima* Ledeb., three-year-old *T. ramosissima*., *Lycium barbarum* L. and *Atriplex canescens* (Pursh) Nutt. were studied using hydrogen and oxygen isotopic compositions during a whole growth period in salinity-affected area of northwest China. Irrigation was applied for comparison of contrasting water conditions on water use of the above shrubs. The result showed that the adult *T. ramosissima* had the phreatophytic nature. The three year old *T. ramosissima* and *Lycium barbarum* L. exhibited higher dependence on water from unsaturated soil in upper profile during early period. The the three year old *Atriplex canescens* was found to have phreatophytic tendency with higher deep water uptake. Apparent depletion in xylem δD values rather than $\delta^{18}O$, compared with water sources, was found. There was discrepancy when using $\delta^{18}O$ or to determine water use uptake by the shrubs. This discrepancy was more obvious after irrigation. Hydrogen isotopic fractionation would occur during water uptake by halophytic shrubs. $\delta^{18}O$ values of xylem water should be adopted to study halophytic shrub water use in salinity-affected regions.

Introduction

Water is a major driver of plant productivity (Gholz *et al.* 1990; Asbjornsen *et al.* 2008). Different water use strategies among species living in a particular habitat are determined by their rooting patterns evolved over the long period of evolution (Dawson *et al.* 1993; Dawson and Pate 1996; Xu and Li 2006). The patterns of water uptake by woody species are summarized as either using only deep soil water or tapping both shallow and deep layers (Dodd *et al.* 1998; Williams and Ehleringer 2000; West *et al.* 2007; Goldstein *et al.* 2008; Guevara *et al.* 2010). Based on this finding, a terminology "phreatophyte" (the species that extract water from aquifers or the capillary fringe above the water table) has come into being and been widely cited (Busch *et al.* 1992; Lin *et al.* 1996; Gries *et al.* 2003; Lite and Stromberg 2005; Eggemeyer *et al.* 2009). According to the extent of this dependence, phreatophytes are classified as either "obligate" (plants that utilize only shallow alluvial groundwater) or "facultative" (plants that have the ability to utilize sources in addition to alluvial groundwater) (Busch *et al.* 1992; Horton *et al.* 2003).

Tamarix has been listed as facultative phreatophyte, it utilizes only groundwater when this water source is shallow and relatively constant in depth, but is also able to extract water from unsaturated soil by its greater root allocation and physiological adaptability to a higher degree of water stress when groundwater is deeper and temporally more variable in depth (Busch *et al.* 1992; Busch and Smith 1995; Smith *et al.* 1998; Horton *et al.* 2001). However Horton *et al.* (2003) did not find water use from the unsaturated soil by *Tamarix* grown in a series of sites with a groundwater gradient from 0 m to 4.4 m. Xu *et al.* (2006) reported *Tamarix ramosissima* ("saltcedar") relied mostly on groundwater for survival and did not show a significant photosynthetic response to sustained drought or heavy rain pulse event.

Atriplex canescens ("four-wing saltbush"), known as xerohalophyte, has been reported to have deep root indices, vulnerable shallow roots, uniformly high ψ throughout the summer, suggesting preferential use of more stable deep soil water and phreatophytic tendency (Sperry and Hacke 2002).

Lycium barbarum L. ("wolfberry") is the only halophytic plant of the *Lycium* group in Solanaceae family, which is distributed in northwest China, middle Asia and South America (Wei *et al.* 2006). There has been little information published about the water use of *Lycium barbarum* L.

The source regions of soil water uptake by plants have traditionally been difficult to assess (Ehrlinger and Dawson 1992) and excavation of roots to determine their spatial distribution is destructive and time consuming (Meinzer *et al.* 2001). With the development of stable isotope techniques, natural abundance of stable isotopic ratios of hydrogen (δD) and oxygen ($\delta^{18}O$) has been used as a tracer to determine the source of water extracted from soil by plant (Dawson 1993). The use of stable isotopes at natural abundance levels in determining the plant water sources is based on two assumptions. Firstly, the isotopic composition of the soil water must vary with depth. This gradient is related to the isotopic composition of rain water that recharges the soil profiles, the isotopic composition of the ground water and the isotopic fractionation occurring during evaporation near the soil surface (Ehrlinger and Dawson 1992; Picon-Cochard *et al.* 2001). Secondly, there is no fractionation of water isotopes during root water uptake and transport to the stem (White *et al.* 1985; Dawson and Ehleringer 1991; Thorburn and Mensforth 1993). Therefore, the water source of plants can be identified by simultaneously analyzing the isotopic composition of xylem sap and soil water.

However, several reports indicate that some mangrove species and halophytes fractionate hydrogen isotopes during water uptake resulting in xylem water being depleted in deuterium relative to source water. The degree of hydrogen isotope fractionation during water uptake in halophytes was positively correlated with growth and transpiration rates (Lin and Sternberg 1993; Ellsworth and Williams 2007). The authors hypothesized that the deuterium depletion in halophytes occurs resulting from the special anatomic structure of their root endodermis (with developed Casparian strip on the radial cell walls) compared with the terrestrial glycophytes. When water moved symplastically rather than apoplastically through the endodermis, the fractionation in hydrogen isotopes in water occurred (Lin and Sternberg 1993)). Symplastic pathway of water requires dissociation of large aggregates of water molecules before crossing the plasma membrane in the root endodermis. Since the difference in vibrational energy between ^2H and ^1H in water is bigger than that between ^{18}O and ^{16}O, the fractionation of isotopes in water during uptake by roots is more apparent for hydrogen than oxygen. Caution should be taken when using hydrogen isotope to examine source-water use in halophytic and xerophytic species. No fractionation of oxygen isotopes occurred in water during uptake for the same species that fractionated ^2H. $\delta^{18}O$ values of xylem water of a given species accurately reflect the $\delta^{18}O$ values of the soil water (Ellsworth and Williams 2007).

A large number of reports concentrating on the water source, water use strategy and plant-water relations of plants using stable isotopic compositions have covered several ecological systems: riparian areas (Dawson and Ehleringer 1991; Shafroth *et al.* 2000; Horton *et al.* 2003; Chimner and Cooper 2004; Lite and Stromberg 2005), desert regions (Sperry and Hacke 2002; Gries *et al.* 2003; Xu and Li 2006), woodland (Lin *et al.* 1996; Picon-Cochard *et al.* 2001) and grassland (Asbjornsen *et al.* 2008; Eggemeyer *et al.* 2009). The information about water use strategies of halophytes, *Tamarix ramosissima* Ledeb., *Atriplex canescens* (Pursh) Nutt. and *Lycium barbarum* L. in salinity and alkalinity affected regions is scarce. Furthermore, the reported researches were conducted at the sites where groundwater table was not beyond the root range of *T. ramosissima*. Under such circumstance, the conclusion could not be necessarily drawn that *T. ramosissima* does not use water from upper unsaturated soil.

Yinchuan Plain is located in the southeastern area of Huanghe Alluvial Plain. Huanghe River flows through Yinchuan Plain, from southwest to northeast, and widespread irrigation web has been well established (Chen *et al.* 2003). Soil salinity has plagued irrigated lands along the Yellow River in the northern area of Yinchuan Plain shortly after the first canal was built in BC 214. Such factors, i.e. high groundwater table mainly caused by over-irrigation, leaky canals, inadequate drainage system, flatness of the terrain, and high level of the Yellow River during the flood season have contributed to an increase in soil salinity. Low rainfall and strong evaporation also aggravate this ecological problem in this area (Xiong *et al.* 1996).

In this work, we chose a stand consisting of three-year-old shrubs, namely, *Tamarix ramosissima*, *Lycium barbarum* L. and *Atriplex canescens* and a 20-year-old *Tamarix ramosissima* stand for studying the water use strategy of these species. Irrigation was applied once during the peak summer for observing the change in water use of the shrubs grown in the contrasted water regimes. The discrepancy in determining water uptake rate of shrubs using hydrogen or oxygen isotopic compositions in different water conditions was also analyzed. The specific objectives of this study are: i) To quantify water uptakes of the above mentioned shrubs from different soil profiles prior to and after irrigation by using D and ^{18}O isotopic composition; ii) To assess the accuracy of hydrogen and oxygen isotopic composition in terms of reflecting water sources of halophytic shrubs under water-limited and well-watered soil conditions.

Materials and methods

Site description

The study was conducted at Xidatan, Ningxia, China (1089 m in altitude, 106°30′9″ E□38°52′33″ N). Xidatan is located in the northern area of Yinchuan Plain. Flat terrain makes it difficult to drain water from lands in this area; thus, salinity has arisen. The groundwater table is shallow with salt concentration from 1.3 g/L to 1.4 g/L. Mean annual rainfall is 172.5 mm, mean annual evaporation is 1755 mm. The groundwater table was 2.5 m to 2.8 m during plant growth period. A stand consisting of three artificially established shrubs, i.e. *Tamarix ramosissima* Ledeb. *Lycium barbarum* L. and *Atriplex canescens* (Pursh) Nutt. , was established in 2008. Adult *Tamarix ramosissima* Ledeb. (around 20 years old) natively established nearby was used for comparing the age effect on water uptake of this species.

Application of 120 mm water was done on 26 June. The irrigation water was pumped from a nearby well.

Water source sampling and analysis

Samples of well water, precipitation water, soil water from different depths and groundwater were collected for hydrogen and oxygen isotopic analyses; samples were sealed in glass vials with screw caps and wrapped with parafilm. For determination of plant water source, five individuals were chosen at random. Fully suberized branches on the top of canopy were collected from each plant. The barks and green leaves were eliminated from branches, then the samples were immediately sealed in glass vials in the way described above. Rain water samples were collected after precipitation from May to July. Groundwater was sampled in monitoring wells and well water was sampled in a machine well. Samples of soil and stem were kept frozen at -20 ℃, while rainwater, well water and groundwater samples were stored at 4 ℃ until analysis for hydrogen and oxygen. Samples of soil water, groundwater, and plant water were collected on 6 May, 28 May, 25 June and 4 July. Ground-water depth was measured monthly in monitoring wells. Irrigation (120 mm) was applied 3 days before the second sampling.

For analyzing D and ^{18}O compositions, water in soil and stem was extracted using cryogenic vacuum distillation (Horton *et al.* 2003). H_2O was split into CO and H_2 with catalyst in FLASHEA 1112HT (Thermo Scientific, Germany) isotopic analyzer. DELTA V isotope ratio mass spectrometer (Thermo Scientific, Germany) was used to analyze O in CO and H in H_2 for obtaining the ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$. The δD and$\delta^{18}O$ values were expressed in parts per thousand (%) relative to the V-SMOW standard (Gonfiantini, 1978):

δD or $\delta^{18}O = [R_{(sample)} / R_{(reference)} -1] \times 1000$. Where $R = {}^{2}H/{}^{1}H$ for deuterium, or $R = {}^{18}O/{}^{16}O$ for oxygen.

Soil water content and salinity

Volumetric soil water content was determined by time domain reflectometry technology (TDR Trime-T3, Ettlingen/Baden-Württemberg, Germany). For measuring volumetric water content, a probe was inserted into a 2-m plastic tube, buried vertically in the field in advance, and readings were recorded at intervals of 20 cm. Measurement was made on 6 May, 28 May, 26 June and 4 July. The soil water content was showed in Figure 2. Soil soluble salt content was analyzed by dissolving the soil samples into distilled water to achieve a soil solution, and then drying the solution to obtain the salt residue (Xu and Li 2006).

Statistical analysis

The effects of irrigation treatments and differences between shrubs were tested with factorial ANOVA analyses (GLM procedure of the SAS software package, SAS Institute, Cary, NC), where the F-values were considered statistically significant at $\alpha=0.05$. Pearson phenotypic correlations were calculated to determine the relationship between $\delta^{18}O$ and δD values, water content, salt content and pH in soil profile.

Result

Environmental parameters

Total precipitation for the study period was 112.1 mm. No effective rain occurred in April. Monthly rainfall was 45.9 mm in May and 49 mm in June (Fig. 1). Soil water content (Fig. 2) increased with depth. Highest soil water content was observed in the 160 -180 cm profile. Highest soluble salt content was recorded in the 100-120 cm profile. The upper and deep profiles were characterized by lower soluble salt content. The salt content of groundwater was 1.48 g/L before irrigation and 1.97 g/L after irrigation. The pH values ranged from 7.1 to 8.8 before irrigation and 7-8.3 after irrigation. Irrigation had significant effect on water and soluble salt contents in the 0-140 cm profile (Fig. 2).

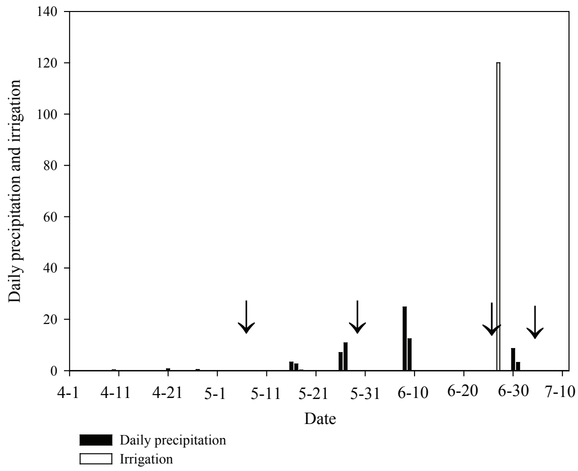

Figure 1: Daily rainfall recorded from 1 April to 5 July, 2010 in Xidatan. Solid columns represent daily rainfall, hollow column represents irrigation. Arrow points to the data when soil water, groundwater and plant xylem water was sampled.

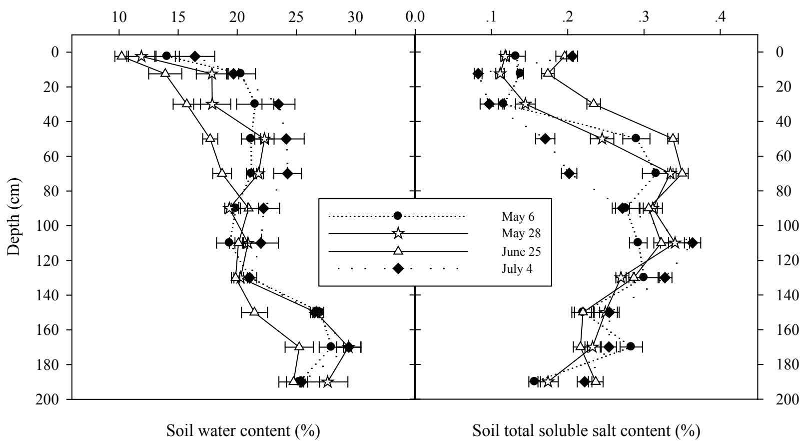

Figure 2: Soil total soluble salt content and water content in soil profile of shrubbery on 6 May, 28 May, 25 June and 4 July, 2010.

Isotope compositions of different water sources and xylem water of different shrubs

Different water sources displayed distinct difference in isotopic signatures. The ranking of δD and $\delta^{18}O$ values was well water < groundwater < rain water (Fig. 3). The isotopic compositions in the upper profile (< 80 cm) fluctuated temporally and spatially. Lower δD and $\delta^{18}O$ values were observed in the deep soil profile (below 140 cm). δD and $\delta^{18}O$ values of deep soil water were close to those of groundwater. Isotopic compositions of soil water above 80 cm sampled on 25 June were more positive compared with those sampled on 6 May and 28 May. Irrigation led to significant decrease in isotopic compositions of soil water in soil profile above 80 cm. A sudden increase in δD and $\delta^{18}O$ values was noted in the 80-100 cm profile after irrigation (Fig. 3).

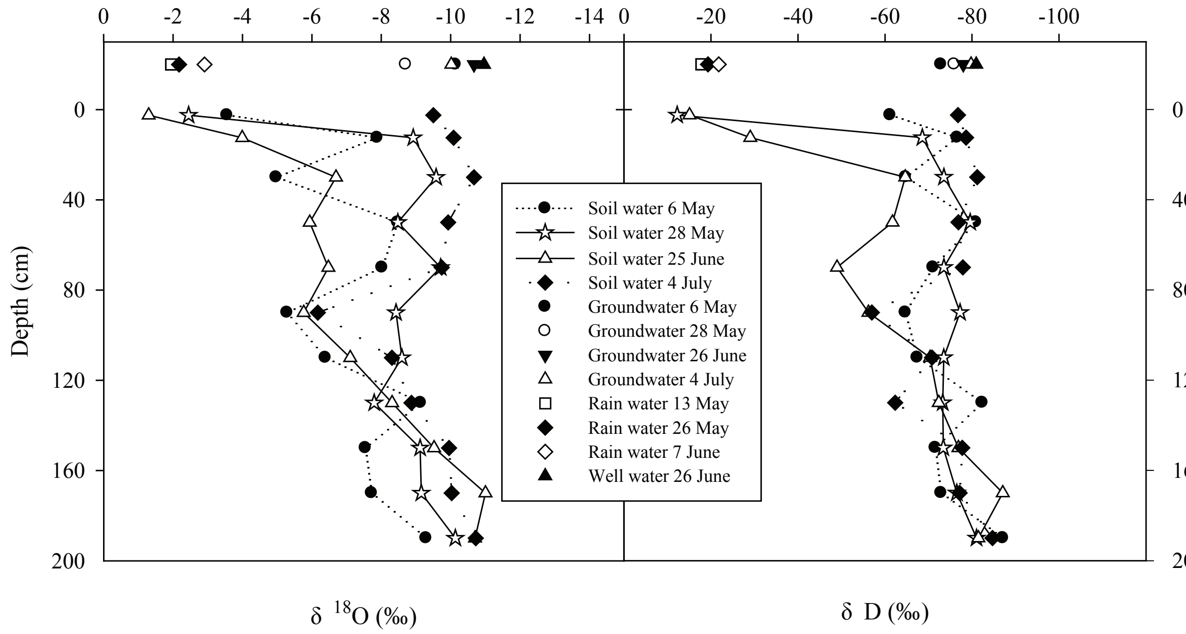

Figure 3: $\delta^{18}O$ and δD values of soil water (0-200 cm), groundwater (GW), well water (WW), and rain water sampled at different periods in Xidatan.

The fractionation processes in different water sources and xylem water of shrubs were evaluated by a $\delta^{18}O$-δD graph. Results showed that almost all the samples of soil water and groundwater plotted at the right side of the local meteoric water line in arid area of Northwest China (ANC LMWL) with the latter plotting nearer to the LMWL than the former, while the well water plotted on the LMWL indicating the effect of evaporation on different water sources. The soil water sampled on 6 May dotted to the right side of the ANC LMWL line, whereas that sampled on 4 July were the closest to the ANC LMWL line, indicating the cumulative evaporative effect on soil water in upper profiles during spring and the effect of well water on the isotopic compositions of soil water (Fig. 4a). $\delta^{18}O$ and δD values of plant xylem sampled on the same date were lower for 20-year-old *T. ramosissima* than the three-year-old shrubs with the former dotting nearer to the ANC LMWL line. Similar with soil water samples, the coordinates of plant xylem water sampled on 6 May were on the right side of the ANC LMWL line. After irrigation, the $\delta^{18}O$ and δD of four shrubs were plotted near to the ANC LMWL line (Fig. 4b).

Relationship among δD, $\delta^{18}O$, soil water content, salt concentration and pH

Significant and positive correlations (correlation coefficients ranging from 0.920 to 0.944) between δD and $\delta^{18}O$ of soil water, sampled on four periods, were recorded. Soil water content correlated negatively with soil water δD (٢٨ May and ٢٥ June) and $\delta^{18}O$ (6 May, 28 May and 25 June). Soil total soluble salt concentration correlated positively with soil water δD and $\delta^{18}O$ after irrigation (4 July) (Fig. 5).

Comparison of xylem $\delta^{18}O$ and δD of shrubs with those of water sources

$\delta^{18}O$ values of plant xylem water overlapped with those of soil water and groundwater during the sampling periods, enabling relatively accurate inferences of water uptake depth for each species. The plant samples that were more enriched in ^{18}O were collected on 6 May and 25 June, the plant xylem samples enriched in ^{2}H were collected on 28 May. Generally, the plant xylem water of 20-year-old *T. ramosissima* was depleted in $\delta^{18}O$ and δD for the whole sampling periods except for 6 May when the δD of three-year-old *A. canescens* was the lowest (Fig. 6-9).

During the sampling periods from 6 May to 4 July in 2010, for three-year-old *L. barbarum*, the $\delta^{18}O$ values ranged from -3.89‰ to -8.64‰, and δD values ranged from -69.75‰ to -80.31‰; for three-year-old *T. ramosissima*, the $\delta^{18}O$ values ranged from -6.59‰ to -8.62‰, and δD values ranged from -64.33‰ to -82.25‰. The $\delta^{18}O$ and δD values of above two species were similar to soil water $\delta^{18}O$ and δD values at 5-20 cm depth during early growth period (6 May and 28 May) and similar to those at 100-140 cm depth during middle and late growth period (25 June and 4 July). The $\delta^{18}O$ (from -8.64‰ to -9.40‰) and δD (from -80.69‰ to -84.61‰) values of 20-year-old *T. ramosissima* were the lowest and similar to $\delta^{18}O$ and δD values of soil water in deep profiles and groundwater. $\delta^{18}O$ and δD values of three-year-old *A. Canescens* were next to 20-year-old *T. ramosissima* on 25 June and 4 July, indicating deeper water uptake for this species during the late growth period (Fig. 6-9).

The xylem δD values of the shrubs were more negative with respect to soil water than were $\delta^{18}O$ values on the four sampling periods, with the magnitude being bigger during the late growth periods, especially after irrigation when the δD values of the four shrubs were more negative than groundwater. δD values of 20-year-old *T. ramosissima* were equal to the most negative δD values in the whole soil profiles on 28 May and 4 July (Fig. 6-9).

Discussion

Seasonal variation in sources of soil water

Using stable isotopes to determining the water sources for plant transpiration depends on sources of water having different endogenous isotopic compositions (Eggemeyer *et al.* 2009). The seasonal input of moisture into the soil, evaporation in the uppermost surface layers, or differences between bulk soil moisture and ground water contribute to the isotopic composition of water within soils (Ehrlinger and Dawson 1992). We observed a vertical gradient in soil water $\delta^{18}O$ and δD profiles. The $\delta^{18}O$ and δD values in 0-80 cm soil profile fluctuated indicating the multiple influences of the input of irrigational water and precipitation and the evaporation. A negative correlation between soil water content and values of $\delta^{18}O$ and δD in 0-200 cm soil profile indicated the significant effects of evaporation and irrigational event (well water being $\delta^{18}O$ and δD-depleted) on the soil isotopic compositions. More negative $\delta^{18}O$ values were found in deep soil profiles than groundwater, reflecting the combinational effects of irrigations applied in current or previous seasons and the recharge of groundwater to the corresponding soil profiles.

After irrigation, a significant decrease in the values of δD and $\delta^{18}O$ above 80 cm soil profile suggested the infiltration of well water (with more negative isotopic composition). Significant and positive correlations between soil salt concentration and values of δD and $\delta^{18}O$ were observed. This may be attributed firstly to the possibility that the δD and $\delta^{18}O$-depleted irrigated water would leach soil salt to the deeper layer and lower the isotopic compositions in the corresponding soil profile; and secondly to the fact that evaporation would cause increase in salt concentration and isotopic enrichment in the upper soil profile. Much unexpected, the highest values of δD and $\delta^{18}O$ appeared in the 80-100 cm soil profile after irrigation. This implied that a "piston flow" might have happened in soil profile after irrigation (Tang and Feng 2001; Eggemeyer *et al.* 2009) and the replacement of "old soil water" with new infiltrating water would recompose the soil isotopic profile. Presumably, being pushed by irrigational water, the upper soil water (δD and $\delta^{18}O$-enriched) would move downward and stop at a certain soil layer, around 100 cm in depth, and enhance the isotopic composition of this layer when the hydraulic gradient is exhausted. A redistribution of the soil salt concentration in the whole soil profile after irrigation was noted, with and inflex at 100 cm depth, suggesting an obvious leaching effect on salt concentration in the profile.

Since the irrigation events occurred frequently in the neighbor fields (mostly paddy crop) during our second sampling time (mid-summer), the isotopic compositions of groundwater, being recharged by the δD and $\delta^{18}O$-depleted well water, was more negative than those before irrigation. The values of δD and $\delta^{18}O$ in the deep profile close to groundwater also decreased on July 4 compared with May 28, which may be accounted for by the effect of capillarity in the area above the aquifer.

Variations in depth of water uptake during different sampling periods

During the early growth periods (in May), the three-year-old shrubs: *L. barbarum* and *T. ramosissima* mostly extracted water from the upper profile, while the 20-year-old *T. ramosissima* mainly used soil water from the middle and deep profiles. The three-year-old *A. Canescens* displayed tendency of deeper water uptake, reflecting the effects of species and age on the water use strategy of shrubs tested. Presumably, the roots of three-year-old *T. ramosissima* have not been developed enough to access water in the deeper soil layers during seedling stage, its growth would highly depend on moisture in the upper soil profile through greater capacity in osmotic adjustment (Busch and Smith 1995; Stromberg *et al.* 1996; Horton *et al.* 2003). In contrast, the 20-year-old *T. ramosissima* mostly used deeper soil water by developing active absorbing roots at depths close to the groundwater table (Xu and Li 2006). Several authors found no irrigation effect on Gs, Ψ_{pre} and Ψ_{mid} of *T. ramosissima* uncovering some physiological bases in relation to its phreatophytic nature (Cleverly *et al.* 1997; Xu and Li 2006), which is in agreement with our observation.

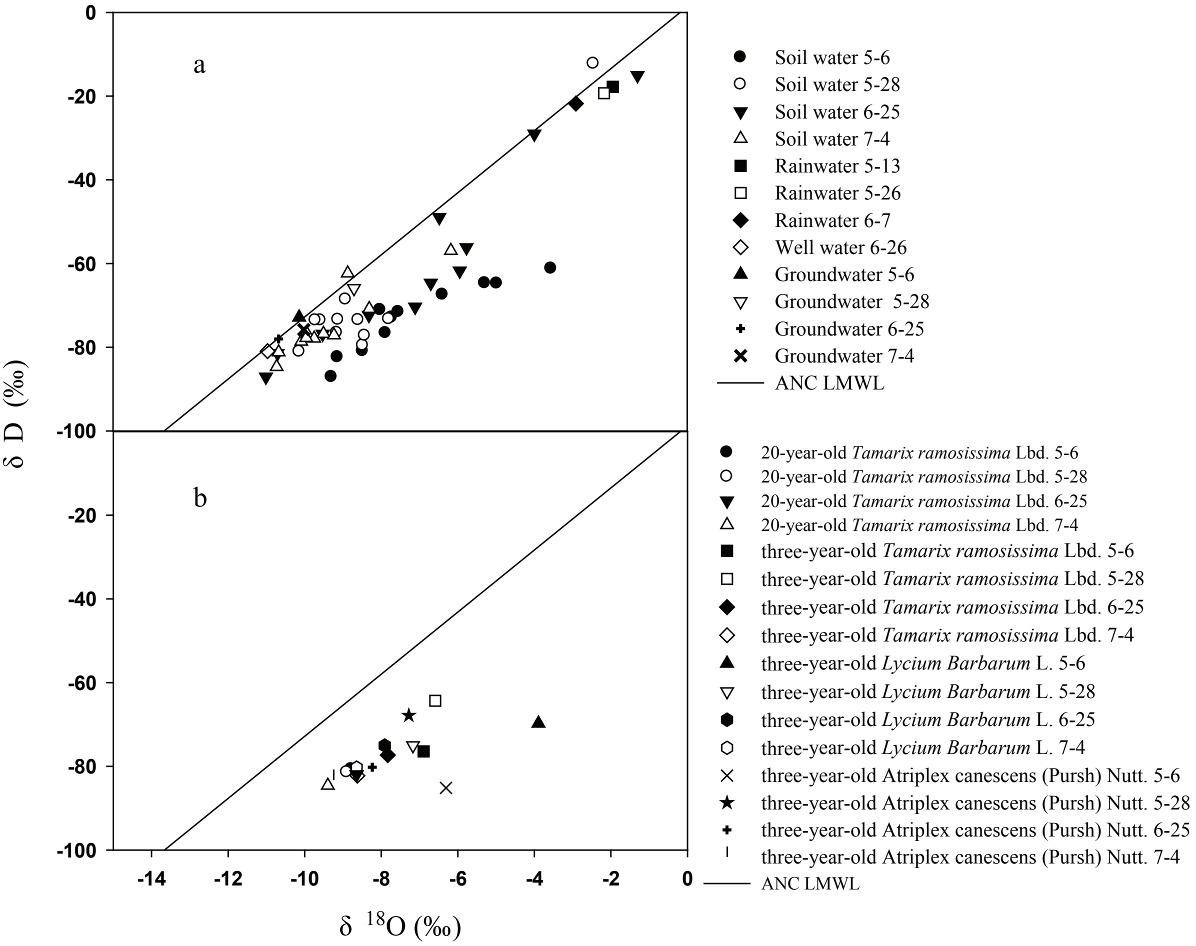

Figure 4 (a-b): $\delta^{18}O$ and δD values of environmental water (a) and plant xylem water (b) sampled at field site and their relationship with Arid Northwest China local meteoric water line (ANC LMWL) in Northwest China.

The three-year-old *T. ramosissima* and three-year-old *L. barbarum* depended heavily on soil water in the middle profile during the late sampling periods (25 June and 4 July), reflecting their rooting depth and irrigational effect. Presumably, the root of the above species did not approach groundwater layer during seedling stage. They had to exploit moisture in the middle profiles during late June when evaporative demand is strong and low water contend in soil surface and "chase" moisture in the middle profile where water content was high after irrigation. This fact also reflected the flexibility of these species for water uptake depth. Our result partly corrected some findings of previous reports that *T. ramosissima* only used deep soil water.

In the present study, *A. canescens* tended to use soil water in the deep profile revealing its phreatophytic tendency and deep root distribution. Sperry & Hacke (2002) reported that *A. Canescens* exhibited phreatophytic tendency and had deepest root indices and vulnerable shallow root. Lin *et al*. (1996) observed *A. Canescens* experienced negative predawn and midday water potentials that were not relieved by summer rain indicating less uptake of rain.

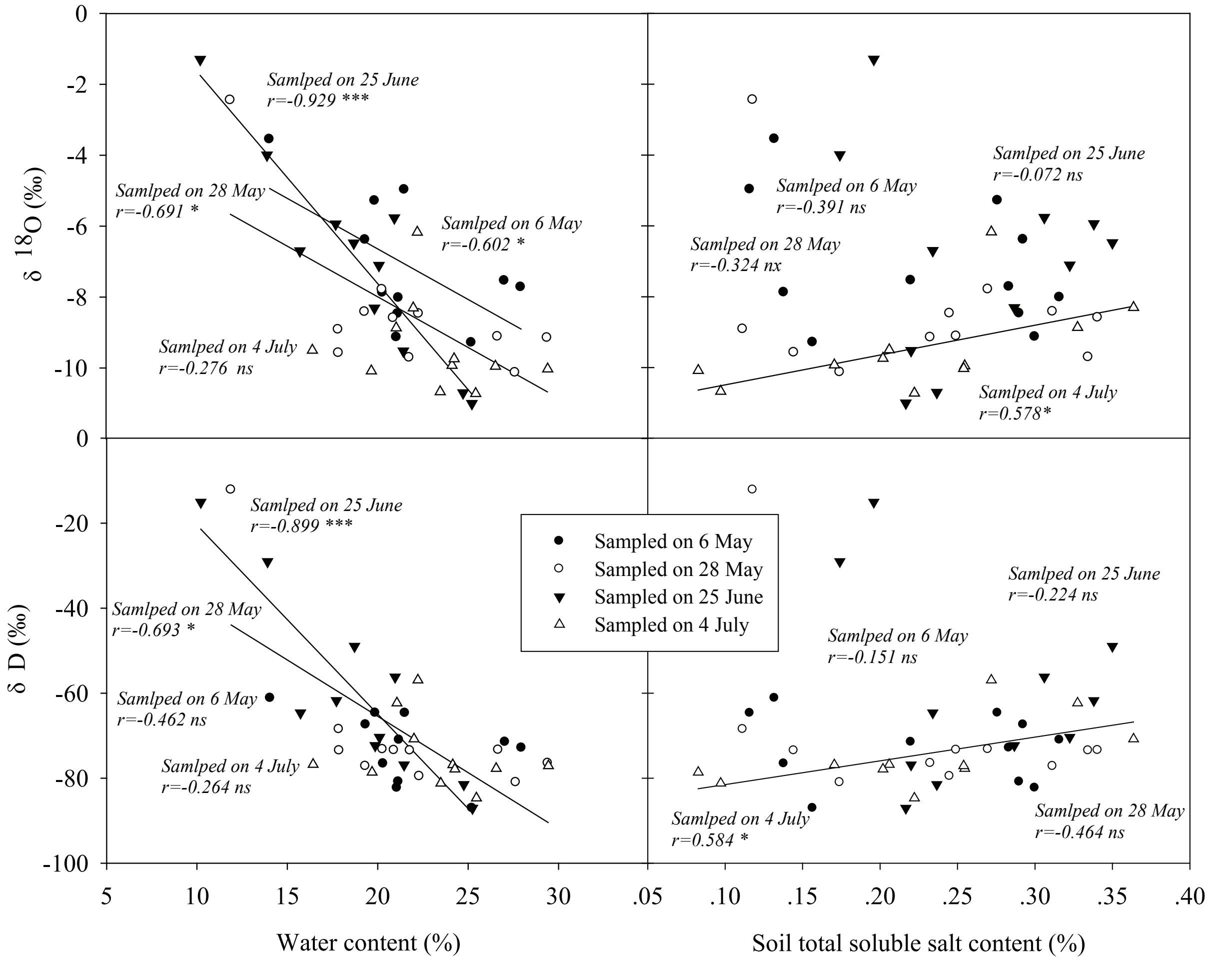

Figure 5: Relationship among soil water hydrogen and oxygen composition, soil water content, soil salt content sampled at different periods.

Analysis for the differences in δ^{18}O or δD between plant xylem water and water sources

Compared with δ^{18}O, more negative δD of plant xylem water relative to soil water and groundwater was observed during our sampling periods, especially after irrigation. What can explain the discrepancy between shrub xylem and potential source δD values? First, there could be some un-sampled water sources with more negative δD values beyond the range of sampling water sources. For our experimental site, the depth to groundwater table was around 250 cm during the sampling period, the deepest sampling depth (200 cm) is near to the groundwater aquifer. The soil profile between 200 cm to groundwater aquifer would almost be saturated and is not suitable for plant root growth. Therefore, there is no likelihood of any un-sampled water source. If there was un-sampled source, δ^{18}O value of a certain shrub would be more negative than the extreme δ^{18}O values of the soil water or groundwater, but it did not.

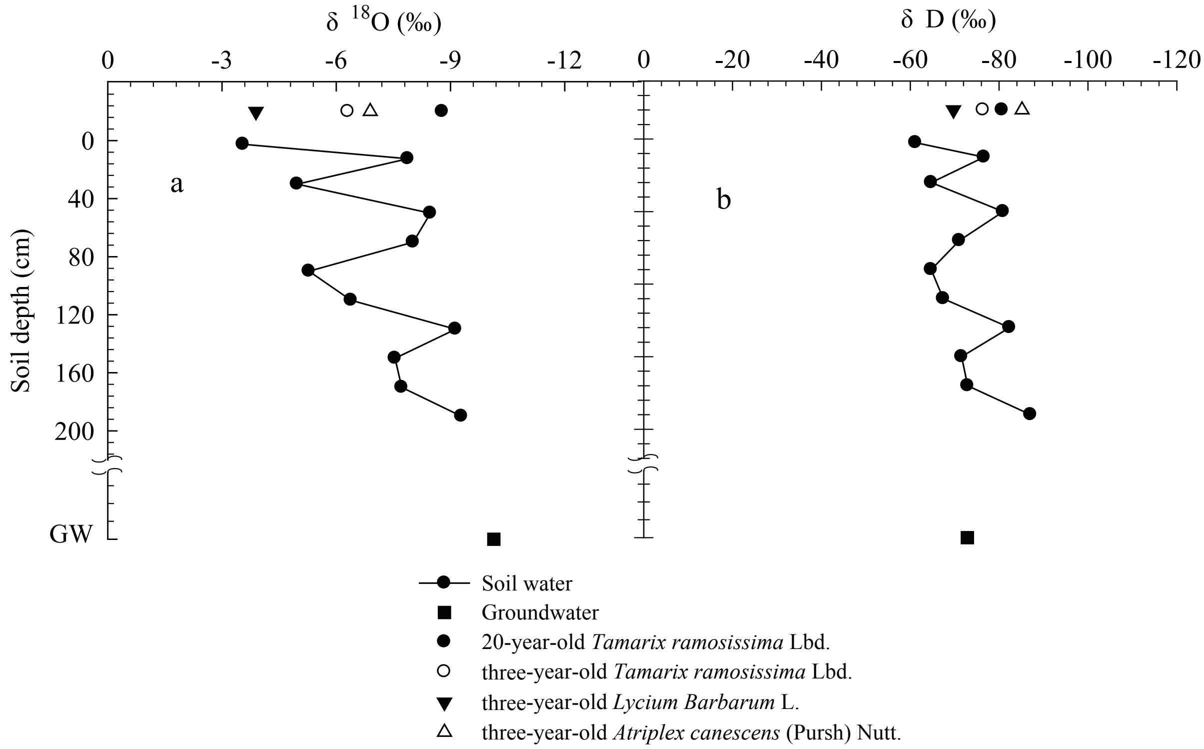

Figure. 6: δ^{18}O (a) and δD (b) values of soil water, groundwater and plant xylem on 6 May in Xidatan.

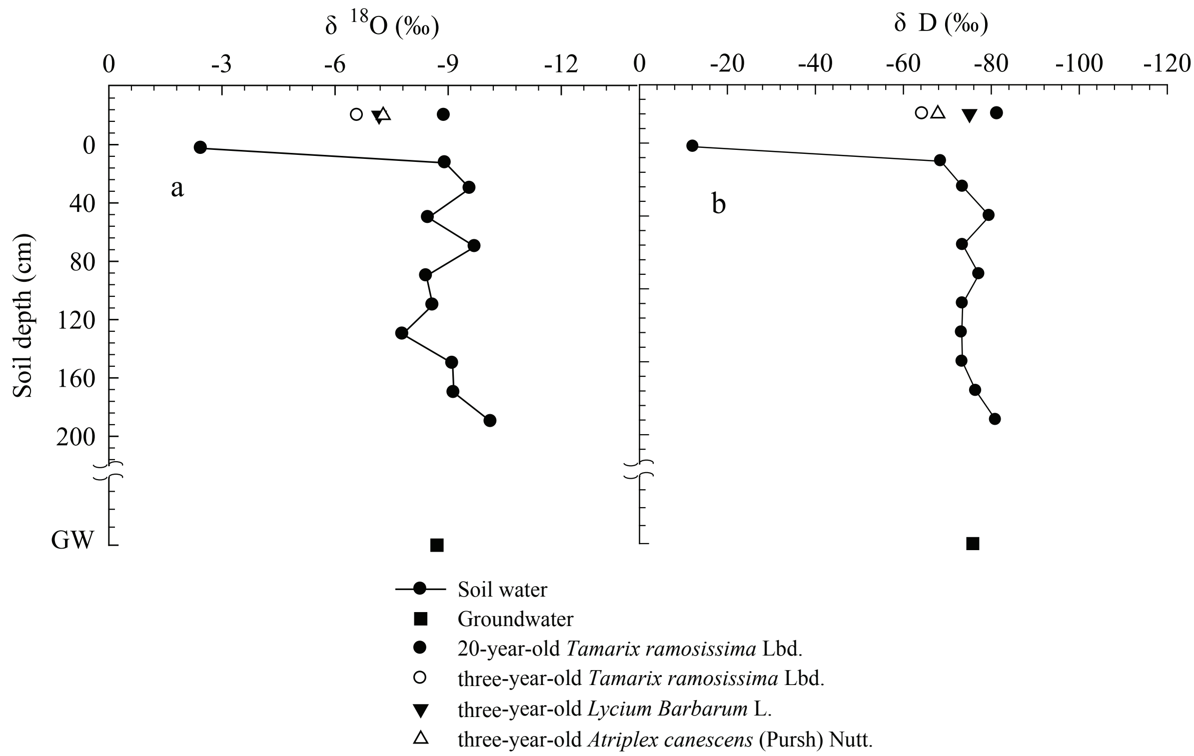

Figure 7: δ^{18}O (a) and δD (b) values of soil water, groundwater and plant xylem on 28 May in Xidatan.

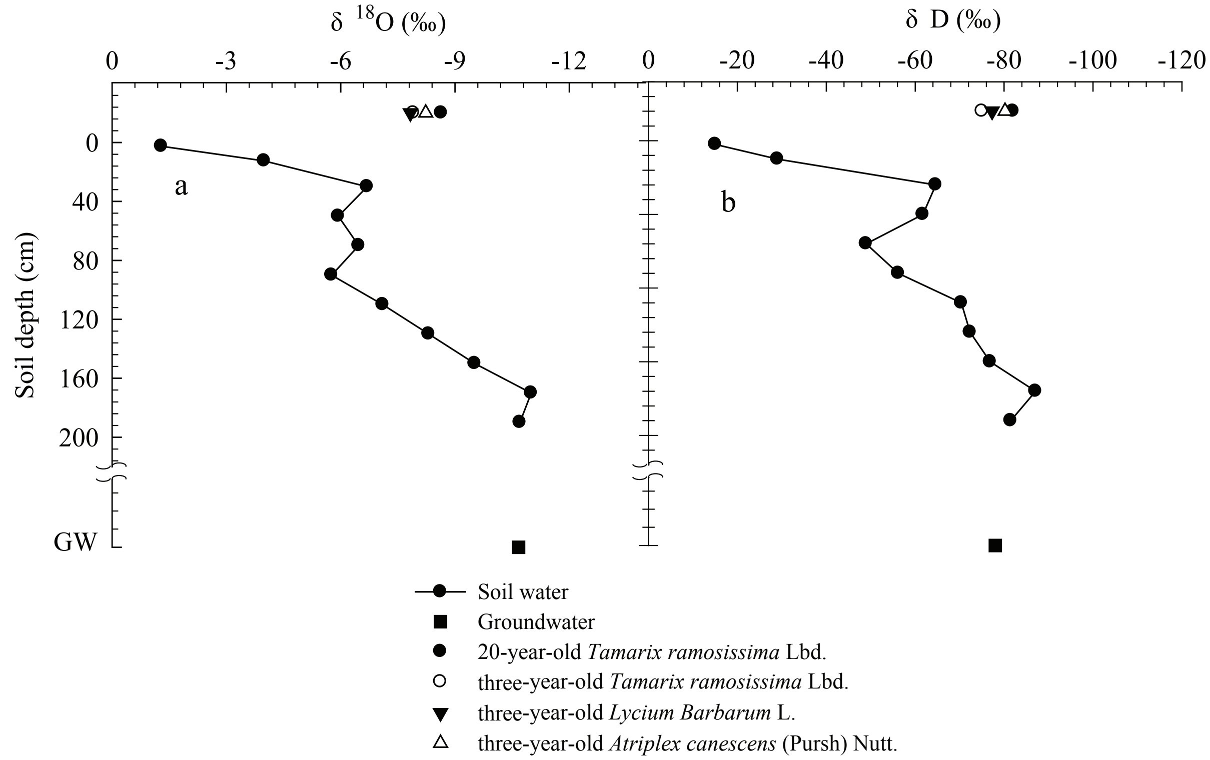

Figure 8: $\boldsymbol{\delta^{18}}$O (a) and δD (b) values of soil water, groundwater and plant xylem before irrigation 25 June in Xidatan.

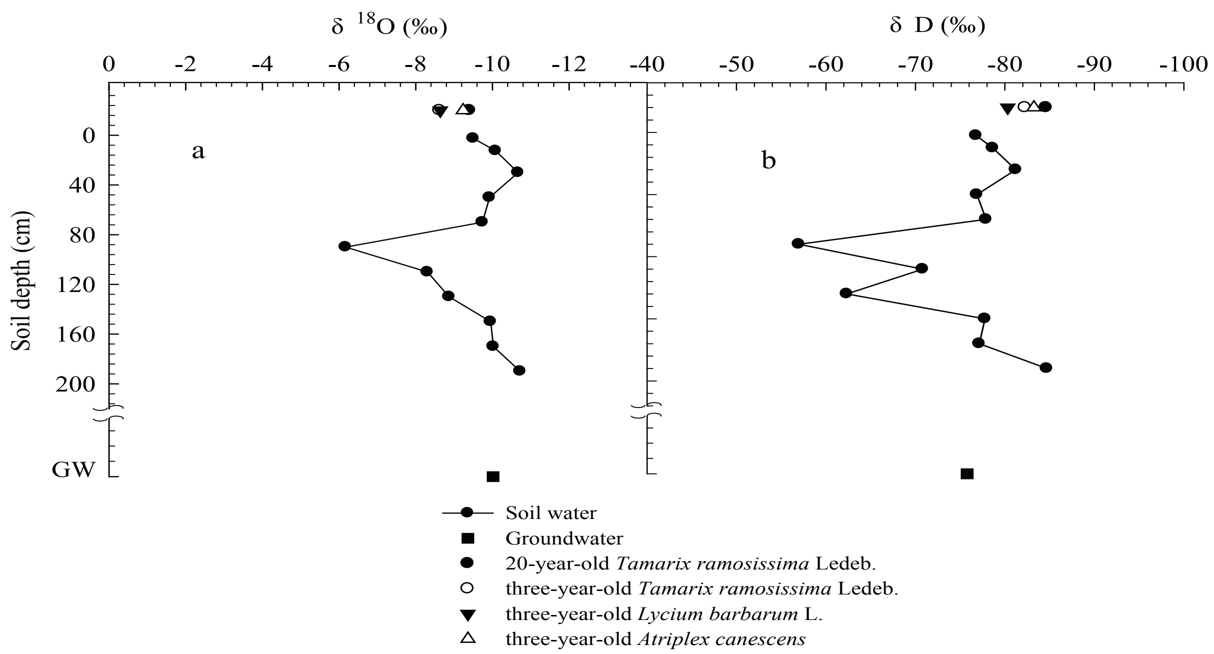

Figure 9: $\boldsymbol{\delta^{18}}$O (a) and δD (b) values of soil water, groundwater and plant xylem after irrigation 4 July in Xidatan.

The possible explanation for the discrepancy of could be the fractionation that occurred during water uptake by these halophytic shrubs. In the present study, compared with $\delta^{18}O$ values, the δD values of the shrubs were lower than soil water δD, implying that the three halophytes, *T. ramosissima*, *A. canescens* and *L. barbarum* might fractionate ^2H during extracting water. Ellsworth and Williams (2007) found 12 of 16 halophytic and xerophytic species exhibiting hydrogen isotope fractionation in water with Δ^2H values ranging from 3 ± 1‰ in *Chrysothamnus nauseosus* to 9 ± 1‰ in *P. velutina*. Horton *et al.* (2003) reported that mean xylem water δD of *Salix gooddingii*, *Populus fremontii*, and *Tamarix* spp. was more depleted than δD of sampled environmental water sources.

Previous documents also reported that the degree of hydrogen isotope fractionation during water uptake in halophytes was positively correlated with growth and transpiration rates (Lin and Sternberg 1993; Ellsworth and Williams 2007). In this study, the decrease in δD values of the shrubs became more apparent during late growth periods when transpiration was intensified due to enhanced temperature and application of irrigation, confirming the above reports.

According to Ellsworth and Williams (2007), depletion of the heavy isotope in stem xylem water was not found for oxygen isotope with xylem $\delta^{18}O$ values accurately reflecting the $\delta^{18}O$ values of the soil water. Therefore, the $\delta^{18}O$ should be adopted to determine water uptake of halophytic shrubs in salinity-affected regions.

Conclusion

A vertical gradient in soil water $\delta^{18}O$ and δD profiles was observed. Evaporation and irrigation have exerted significant effects on soil water oxygen and hydrogen compositions in the soil profiles. The three-year-old *Tamarix ramosissima* Ledeb. and *Lycium barbarum* L. exhibited flexible water use strategy: utilized water from upper unsaturated soil profile during early period and switched water use to middle soil profile during late growth period when water condition was relatively optimal in middle profiles than upper profiles. The 20-year-old *T. ramosissima* heavily depended on middle and deep soil water during the whole growth period. Considering the performances of *T. ramosissima* in different ages, this species is facultative phreatophyte using multiple water sources.

Xylem δD values were more depleted than soil water, pointing to fractionation against ^2H during water uptake for the halophytic shrubs. There was discrepancy when using $\delta^{18}O$ or δD to determine water use uptake by the shrubs. This discrepancy was more obvious when transpiration was greater. $\delta^{18}O$ values of xylem water would accurately reflect the $\delta^{18}O$ values of the water source and should be adopted to study plant water use in salinity-affected regions with shallow groundwater table.

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Yield and water use efficiency of barley under different irrigation scheduling methods in southern Tunisia

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Abstract

In southern Tunisia, having less than 200 mm of annual precipitation, saline shallow ground water is used for irrigation. This study evaluated the effectiveness of the different irrigation scheduling methods and the automatic irrigation by comparing net income with a virtual water price. Barley was cultivated with drip irrigation. First treatment was "full" irrigation (FI) in which amounts required to replenish the root zone to field capacity was applied when the estimated readily available water was depleted. Second and third treatments were 0.7 and 0.5 times of amount but the same timing as first one. Fourth was deficit irrigation but only during maturity stage (DIM50). Fifth was an automatic irrigation system which applied 20 mm water when the monitored water content reached below a threshold value. Sixth was simulated irrigation in which optimized amount of water was applied every 4 days using a numerical model, WASH_2D, that simulates water, solute, and heat transport and crop response in two dimensions. Results showed that automatic and simulated treatments attained higher yields but the total applied depths were also high. The other treatments which applied less depth gave lower yield and net income but water use efficiency (yield per unit irrigation depth) was higher than automatic and simulated irrigation treatments. The highest net income was obtained in automatic irrigation. On the other hand, the highest water use efficiency was obtained in DIM50.

1. Introduction

In arid regions, lack of water resources and salt accumulation in the root zone pose serious problem for people living there as they restrict crop production. Therefore, there is a need to develop methods that help to save water and prevent salt accumulation. Several methods have been developed to save water. Micro-irrigation is one of those methods. Automatic irrigation systems using sensors also have been developed during recent years to precisely meet crop water requirements and respond to drought and salinity stresses. Such "water stat" systems, however, require high initial investment. On the other hand, irrigation scheduling with numerical models, either simple or complicated, does not need to install such instruments, so the cost of irrigation scheduling can be saved. The purpose of this study was to evaluate the effectiveness of different irrigation scheduling methods and that of automatic irrigation by comparing crop yield, water use efficiency, and net income with virtual water price on barley grown under arid climate condition in southern Tunisia.

2. Materials and methods

2.1. Experimental site and design

The experiment was conducted out in a field of the Institut des Régions Arides (IRA) of Medenine in southern Tunisia from November 2011 to June 2012 using a well-drained sandy soil. Soil texture was loamy sand having 85% of sand content, 10% of silt content and 5% of clay content. The bulk density was about 1.61 g/cm^3. Figure 1 shows hydraulic properties measured in the field. The volumetric water content at the field capacity and wilting point was 0.12 and 0.06, respectively. The soil in the profile of 0 – 80 cm had an electrical conductivity of saturated extract (ECe) and pHe of 9.0 dS/m and 6.9, respectively. Ayers and Westcot (1985) have shown that yield reduction of barley due to salt stress starts at 8.0 dS/m. This report suggests that crop might not have been severely suffered by the salinity stress. Organic matter content was less than 8 g/kg. And an accumulation of gypsum was observed from the 50 to 70 cm depth.

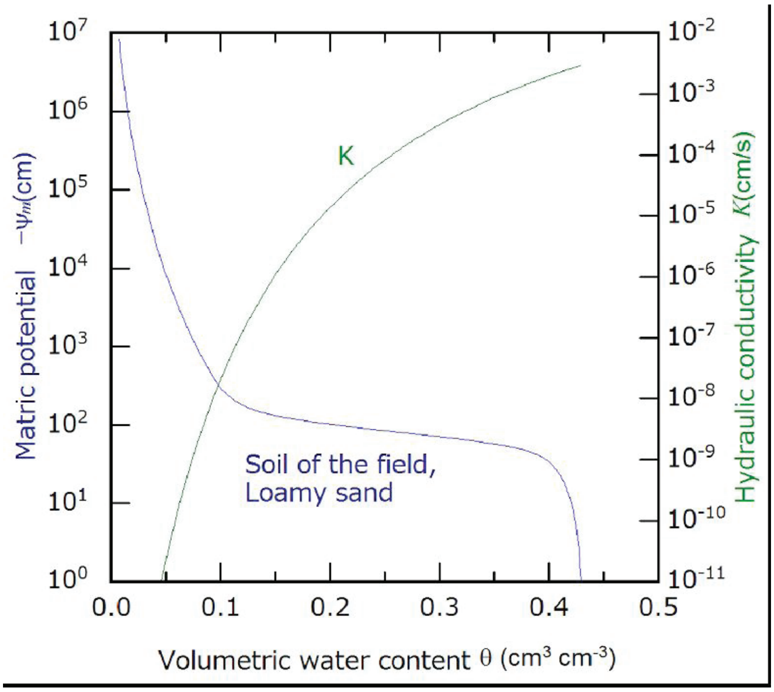

Figure 1: Hydraulic properties in the field.

Barley was cultivated on the line of drip irrigation system. Six irrigation treatments were set up in a randomized block design with three replicates (Figure 2). First treatment was "full" irrigation (FI) in which 100% of water required to refill soil water to field capacity was given when the estimated readily available water in the root zone was depleted. Second and third treatments were 0.7 and 0.5 times of the full irrigation, which was referred as DI70 and DI50, respectively. The fourth was a deficit irrigation applied only during the maturity stage (DIM50). The fifth was an automatic irrigation, in which 20 mm of water was applied when the monitored volumetric water content reached below a threshold value (θ= 0.10). The sixth was a simulated irrigation in which optimized amount of water was applied every 4 days using a numerical model, WASH_2D that simulates water, solute, and heat transport and crop response in two dimensions.

All plots were irrigated with water from a well having water at about 4 m (December 2010) depth and EC ranging from 8.7 to 9.5 dS/m . Two drip lateral lines were used. One was used in FI, DI70, DI50 and DIM50, having a diameter of 16 mm. The emitters were inline type and placed 40 cm apart. The emitters of another line were also inline type but 20 cm apart. Drip irrigation with 20 cm emitters spacing was used for the numerical two dimension model, WASH_2D. These two lines of drip were used to evaluate the effectiveness of different irrigation scheduling methods. A

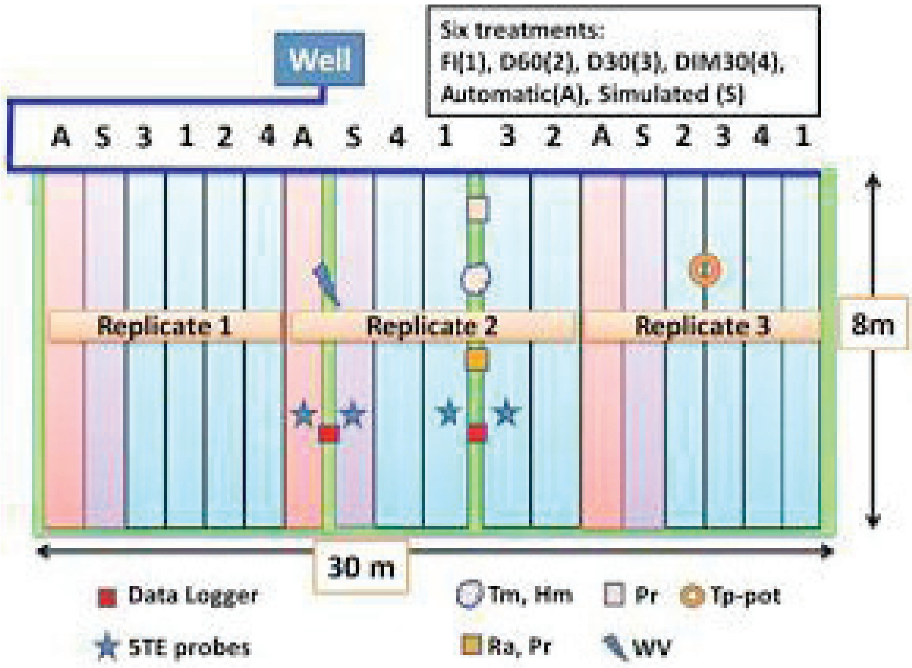

Figure 2: Experimental field design.

drip line for each row of barley was used. A mini-valve set in the lateral was used to control the dripper line.

2.2. Crop management

Barley (*Hordeum vulgar* L.) cultivar 'Ardhaui' was sown on 28 November 2011 in rows 40 cm apart with plants spaced at 5 cm. Soil received 8.3 t/ha of organic manure before the sowing. N, P and K were applied at the rates of 300, 300 and 200 kg/ha, respectively, as per local practices. The P and K fertilizers were applied as basal dose before sowing. Nitrogen was divided and delivered with the irrigation water in all treatments during early vegetative growth stage.

2.3. Sensors

In the simulated, automatic, FI and DI50 treatments, the soil moisture and salinity were monitored using a 5TE probe. The sensors were placed at five points for the simulated and automatic irrigation treatments (Figure 3) whereas at two points for the FI and DI50 (Figure 4).

2.4. Irrigation scheduling

The FAO-56 KcETo (Kc: crop coefficient, ETo: reference evapotranspiration) procedure (Allen *et al.* 1998) was used to predict daily crop evapotranspiration (ETc) as a function of weather data, stage of crop development and water availability. Site and cropping data for the study area are summarized in Table 1. Much of the data were taken from Tables reported in FAO-56 (Allen *et al.* 1998).

Table 1: Site and cropping data for applying the FAO-56 KcETo procedure

Parameters	Value
Growing season period	28 November 2011 – 10 May 2012
Total length of growing stage	165
Lengths of initial / development / mid-season / late-season	36 / 55 / 43 / 31
Kcbini / Kcbmid / Kcend	0.3 / 1.15 / 0.25
Days to attain maximum rooting depth	91
Initial and maximum rooting depths (m)	0.20 / 0.80
p value (%)	50
TAW (mm/m)	98.7

The ETc was estimated daily by using ETo and a Kc. ETo was estimated daily following the Penman-Monteith method given in Allen *et al.* (1998), and Kc was computed following the dual crop coefficient approach that provides for separate calculations for transpiration and evaporation from soil. Kc was the sum of soil evaporation, Ke, and basal crop coefficient, Kcb, reduced by any occurrence of soil water stress, Ks. Kc, Kcb and Ks ranges were 0-1.4, 0-1.4 and 0-1.0, respectively:

$$Kc = KsKcb + Ke$$

Total length of growing season, 165 days, was divided into four sections. The period of initial, development, mid, and late growing season was 1-36 days, 37-91 days, 92-134 days and 135-165 days after sowing, respectively. Kcb during initial season (Kcbini), Kcb during development season (Kcbdev), Kcb during mid-season (Kcbmid) and Kcb during late-season (Kcblate) were assumed as 0.3, 0.3-1.15, 1.15 and 0.25-1.15, respectively. Effective rooting depth of barley during the initial season and the maximum rooting depth during mid-season were assumed as 0.2 m and 0.8 m, respectively.

In the Full Irrigation treatment (FI), irrigation was applied with a quantity equal to 100% of water required to refill soil water to the field capacity, when estimated readily available water in the root zone (RAW) was depleted. RAW is given by:

$$RAW = pTAW$$

where TAW (mm) represents total available water in the root zone. The value p is the fraction of TAW and equal to 0.5 in this experiment (Table 1). TAW is given by:

$$TAW = (\theta_{FC} - \theta_{\wp}) \cdot Bd \cdot Zr$$

where θ_{FC} and $\theta_{\wp}$ is the water content at field capacity and at wilting point, respectively, Bd is the bulk density (g/cm^3), and Zr is the effective rooting depth (mm).

Deficit irrigation 70 (DI70), and Deficit irrigation 50 (DI50) were equal to 0.7 and 0.5 times of the FI. And in DIM50, irrigation was applied at the same quantity as in DI50 but only during the maturity stage. Irrigation for all these four treatments was applied on the same day.

For automatic irrigation, average water content at two critical points in the root zone was measured every morning and when their values were below a threshold (θ=0.10), 20 mm of water was applied.

For simulated irrigation the numerical simulation of two-dimensional movement of water, heat and solute in the soil and plant response to them was carried out using WASH_2D code (http://www.alrc.tottori-u.ac.jp/fujimaki/download/WASH_2D). It solves the two-dimensional Richards' equation including water vapor movement and convection-diffusion equation (CDE) for .solute and heat movement with the finite difference method

The two-dimensional water balance equation for the combined liquid and gaseous phases is given by

$$\frac{\partial \theta}{\partial t} = -\left(\frac{\partial q_{lx}}{\partial x} + \frac{\partial q_{lz}}{\partial z}\right) - \left(\frac{\partial q_{vx}}{\partial x} + \frac{\partial q_{vz}}{\partial z}\right) - S$$

where θ is volumetric water content, t is time (s), ql is the liquid water flux (cm s^{-1}), qv is the water vapor flux (cm s^{-1}), x is horizontal distance, z is depth (cm), and S is a sink term. Subscripts x and z refer to direction of each flux.

The liquid water flux, ql, is described using Darcy's law:

$$q_{lx} = -K \frac{\partial \psi}{\partial x}$$

$$q_{lz} = -K \left(\frac{\partial \psi}{\partial z} - 1\right)$$

where K is the hydraulic conductivity (cm s^{-1}) and ψ_w is the metric potential (cm).

Water vapor flux is divided into two terms due to water-potential and thermal gradient. And latter term is multiplied by mechanical enhancement factor η to incorporate the "liquid island" effect (Phillip and de Vries 1957).

$$q_{vx} = -a\tau \rho_w^{-1} h_r D_{va} \left\{\frac{\rho_{vsat}}{R_v T_s} \frac{\partial \psi_w}{\partial x} + \eta \frac{\partial \rho_{vsat}}{\partial T_s} \frac{\partial T_s}{\partial x}\right\}$$

$$q_{vz} = -a\tau \rho_w^{-1} h_r D_{va} \left\{\frac{\rho_{vsat}}{R_v T_s} \frac{\partial \psi_w}{\partial z} + \eta \frac{\partial \rho_{vsat}}{\partial T_s} \frac{\partial T_s}{\partial z}\right\}$$

where a is the air-filled porosity, t is the tortuosity for gas transport, D_{va} is the diffusion coefficient of water vapor in free air (g $cm^{-2}s^{-1}$), and ρ_w is the density of water (0.997 g cm^{-3} at 25°C), h_r is the relative humidity, ψ_w is the water potential (cm), η is the enhancement factor for thermal water

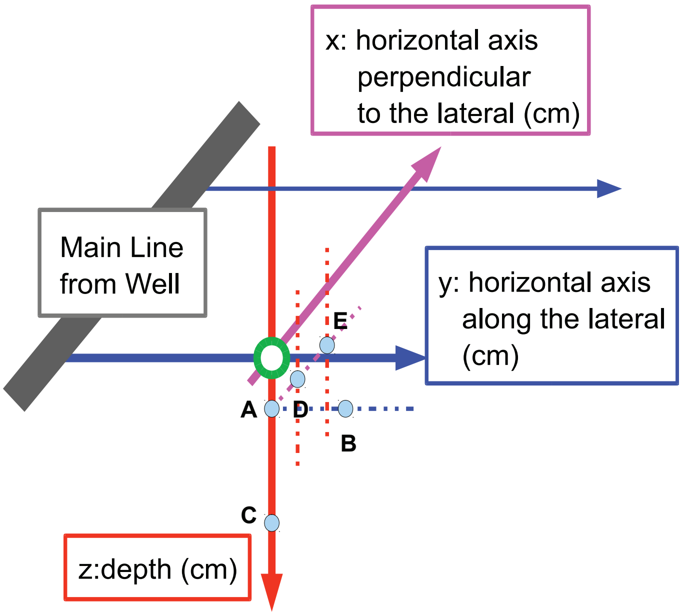

Figure 3: Coordinates (x, y, z) of the sensor position of simulated and automatic treatments.

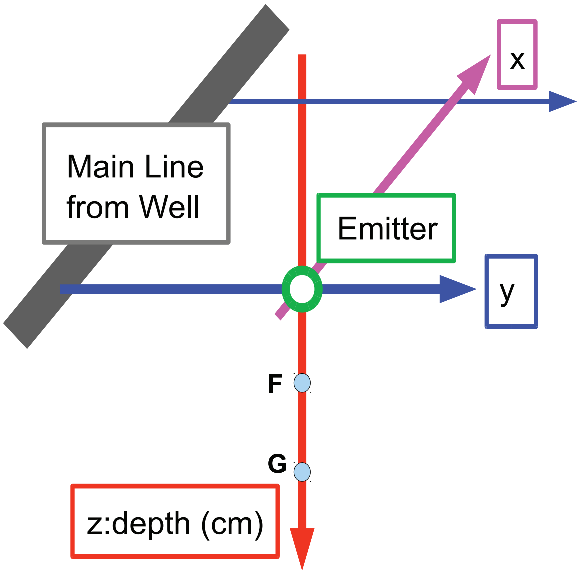

Figure 4: Coordinates (x, y, z) of the sensor position of FI and DI50 treatments.

vapor movement, ρ_{vs} is the saturated water vapor density (g cm^{-3}), T_s is soil temperature (K),, and R_v is the gas constant for water vapor (4697 cm K^{-1}). Assuming thermodynamic equilibrium between the liquid and gaseous phases, the relative humidity in a soil (h_r) or at the soil surface (h_{rs}) can be calculated using:

$$h_r = \exp\left(\frac{\Psi_w}{R_v T}\right)$$

The two-dimensional solute balance is given by

$$\frac{\partial(\theta c)}{\partial t}=-\left(\frac{\partial q_{sx}}{\partial x}+\frac{\partial q_{sz}}{\partial z}\right)+S_c \quad s=0\cap c<c_{max}$$

where c is the concentration of the solute (mg cm^{-3}), qs is solute flux density (mg cm^2 s^{-1}), s is the mass of crystal per unit volume (mg cm^{-3}), c_{max} is the saturated concentration (mg cm^{-3}). If precipitation and dissolution are assumed to occur instantaneously, s is calculated by

$$\frac{\partial s}{\partial t}=-\left(\frac{\partial q_{sx}}{\partial x}+\frac{\partial q_{sz}}{\partial z}\right)+S_c-c_{max}\frac{\partial\theta}{\partial t}$$

$$\frac{\partial c}{\partial t}=0$$

$$s>0\cap c=c_{max}$$

Solute fluxes were calculated by the convection-dispersion equation (CDE):

$$q_{sx}=-\theta D_{xx}\frac{\partial c}{\partial x}-\theta D_{xz}\frac{\partial c}{\partial z}+q_{lx}c \qquad q_{sz}=-\theta D_{zz}\frac{\partial c}{\partial z}-\theta D_{zx}\frac{\partial c}{\partial x}+q_{lz}c$$

where D is the dispersion coefficient (cm^{2}s^{-1}) and first and second subscripts refer to direction of flux and concentration gradient, respectively. Dispersion coefficient for each direction is given by:

$$\theta D_{xx}=\theta D_{iw}\tau_s+\frac{\lambda_L q_{lx}^2+\lambda_T q_{lz}^2}{|q|}$$

$$\theta D_{zz}=\theta D_{iw}\tau_s+\frac{\lambda_L q_{lz}^2+\lambda_T q_{lx}^2}{|q|}$$

$$\theta D_{xz}=\theta D_{zx}=\frac{(\lambda_L-\lambda_T)q_{lx}q_{lz}}{|q|}$$

where Diw is the ionic diffusion coefficient, and τs is the tortuosity factor for ionic diffusion, λ_L is longitudinal dispersivity (cm), and λ_L is transversal dispersivity (cm).

Heat conservation is described as

$$C_{hs}\frac{\partial T_s}{\partial t}=-\left(\frac{\partial q_{hx}}{\partial x}+\frac{\partial q_{hz}}{\partial z}\right)+L\rho_w\left(\frac{\partial q_{vx}}{\partial x}+\frac{\partial q_{vz}}{\partial z}\right)$$

where C_{hs} is the heat capacity of soil (J cm^{-3}K^{-1}), q_h : sensible heat flux (Wcm^{-2}), L : latent heat of water (J g^{-1}). Heat flux for each direction is given by

$$q_{hx}=-k_h\frac{\partial T_s}{\partial x}+C_{hw}T_s q_{lx}$$

$$q_{hz} = -k_h \frac{\partial T_s}{\partial z} + C_{hw} T_s q_{lz}$$

where C_{hw} is the heat capacity of water (4.18 cm^{-3}K^{-1}) and k_h is the thermal conductivity of soil (W cm^{-1} K^{-1}) .

Evaporation rate (E) was calculated by a bulk transfer equation:

$$E = \frac{\tilde{n}_{vss} h_{rs} - \tilde{n}_{vsa} h_{ra}}{r_a + r_{sc}}$$

where ρ_{vss} is the saturated vapor concentration at the soil surface (g cm^{-3}), ρ_{va} is the saturated vapor concentration at reference height (g cm^{-3}), h_{rs} is the relative humidity at the soil surface (g cm^{-3}), h_{ra} is the relative humidity at reference height, r_a is the aerodynamic resistance (s cm^{-1}) and r_{sc}, is the resistance due to salt crust (s cm^{-1}). For uniform bare field, r_a is calculated from wind velocity at the hight of 2m, u_2(cm s^{-1})(van Bavel and Hillel, 1976).

$$r_a = \frac{\ln\left(\frac{200}{z_m}\right)^2}{\kappa^2 u_2}$$

where z_m is surface roughness (cm) and κ is Karman constant(0.4). An increase in aerodynamic resistance due to plant cover was also expressed as a function of leaf area index.

$$r_a = r_{a0}(1 + a_{ra} I)$$

where r_{a0} is r_a of bare soil surface and a_{ra} is a plant-specific parameter.

Heat flux at the soil surface is given by the heat balance equation considering convective heat transfer by rainfall and irrigation.

$$q_{h0} = (1 - \alpha_r) R_a + R_l - L q_{v0} - C_{ha} \frac{T_{s0} - T_a}{r_a} + C_{hw} T_w q_{l0}$$

where R_a is the short-wave radiation flux(Wcm^{-2}), R_l is the long-wave radiation flux(Wcm^{-2}), α_r is the albedo, T_a is temperature at the reference height (K), T_w is the temperature of infiltrating water or soil surface. Subscript 0 indicates value at the soil surface. Subscript 0 indicates value at the soil surface. Since shortwave radiation flux which arrives at the soil surface is decreased due to vegetation cover, the shortwave flux is expressed as a function of leaf area index.

$$R_s = R_{sc} \exp(-a_{Rs} I)$$

where R_{sc} is R_s at canopy and a_{Rs} is a plant-specific parameter.

The transpiration rate, T, is computed by integrating the water uptake rate, S, over the root zone:

$$T = \int_0^L \int_0^W S\,dx\,dz$$

where L and W are depth and width of the calculated zone, respectively. Feddes *et al.* (1978) specified S as

$$S = T_p \beta \alpha_w$$

where $T_{p,}$ b and α_w are the potential transpiration rate (cm s^{-1}), normalized root density distribution (cm^{-2}) and reduction coefficient, respectively. T_p is given by multiplying the reference evapotranspiration rate (E_p, cm/s) using the Penman-Monteith equation (Allen *et al.* 1998) and crop coefficient (K_c).

$$T_{rp} = W E_p K_c$$

The root activity b was described as:

$$\beta = 0.75(b_{rt}+1)d_{rt}^{-b-1}(d_{rt}-z)^b g_{rt}(1-x^2 g_{rt}^{-2})$$

where b_{rt} is a fitting parameter, and d_{rt} and g_{rt} are depth and width of the root zone (cm).

Reduction coefficient α_w is a function of matric and osmotic potential. This function is called as stress response function. WASH_2D uses so-called additive form stress response function:

$$\alpha = \frac{1}{1+\left(\frac{\psi}{\psi_{50}}+\frac{\psi_o}{\psi_{o50}}\right)^p}$$

where y_{50}, ψ_{O50}, and p are fitting parameters.

Since K_c depends mainly on leaf area and leaf area may be a function of cumulative transpiration, K_c is expressed as a function of cumulative transpiration:

$$K_c = a_{kc}[1-\exp(b_{kc}\Sigma T_r)]+c_{kc}$$

where a_{kc}, b_{kc} and c_{kc} are fitting parameters. The d_{rt} is also expressed as a function of cumulative transpiration:

$$d_{rt} = a_{drt}\left[1-\exp\left(b_{drt}\int T_r dt\right)\right]+c_{drt}$$

where a_{drt}, b_{drt} and c_{drt} are fitting parameters. Leaf area index (I) is also expressed as a function .of cumulative transpiration

$$I = a_{LAI}\left[1-\exp\left(b_{LAI}\int T_r dt\right)\right]$$

where a_{LAI} and b_{LAI} are fitting parameters.

2.5. Soil water content and salinity

Soil samples were taken every 20 cm to a depth of 80 cm, at four points as shown in Figure 5, and measured before, during growing season, and at harvest to monitor soil water content and salinity in FI, DI70, DI50 and DIM50.

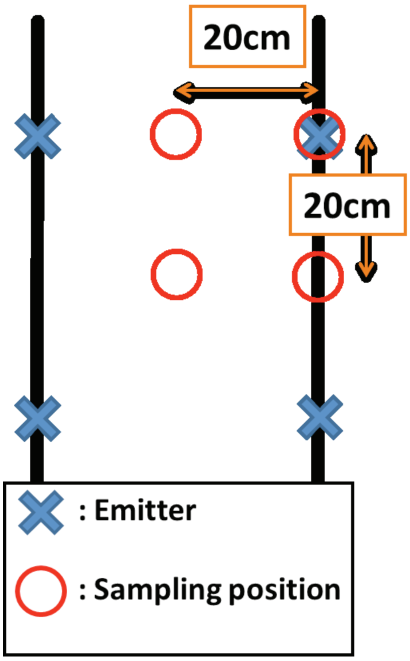

Figure 5: Sampling position.

2.6. Yield

Barley was harvested at the end of May, 2012. In FI, DI70, DI50 and DIM50 treatments, all plant samples of every elementary plot were harvested by hand to evaluate the grain yield and above-ground dry matter. Some of them were also taken to measure 1000-seed weight, seed per spike and spike per square meter. In the case of the automatic and simulated irrigation treatments, randomized plants of each elementary plot were harvested by hand to evaluate the grain yield and dry matter.

2.7. Water use efficiency

Water use efficiency (WUE) was defined as the yield per unit of water consumed, whether it coming from irrigation (IWUE) or total supply (TWUE) including the precipitation.

2.8. Net income

Income was equal to grain yield multiplied by barley price. The water cost was equal to the irrigation water applied multiplied by a virtual price of water. Net Income was the difference between income and cost.

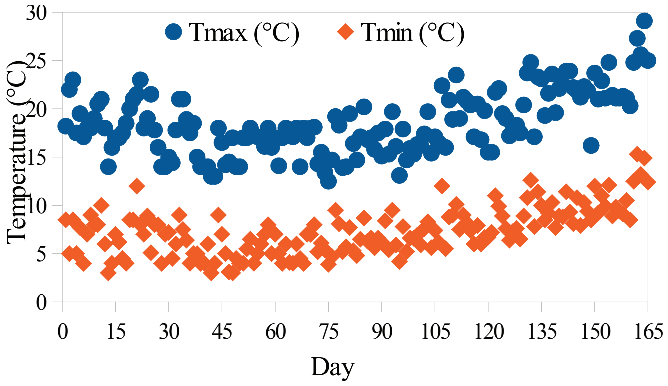

Figure 6: Daily maximum (Tmax) and minimum (Tmin) temperatures during the growing season.

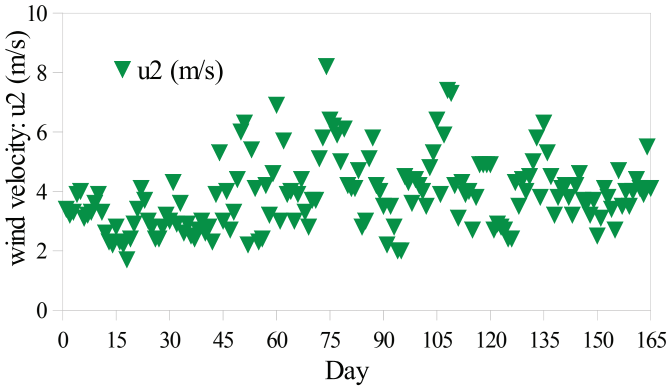

Figure 7: Daily wind velocity (u2) during the growing season.

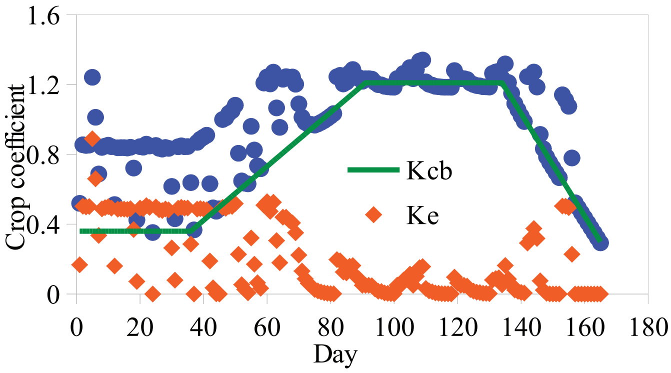

Figure 8: Crop coefficient curves for barley (28 Nov 2011 – 27 May 2012).

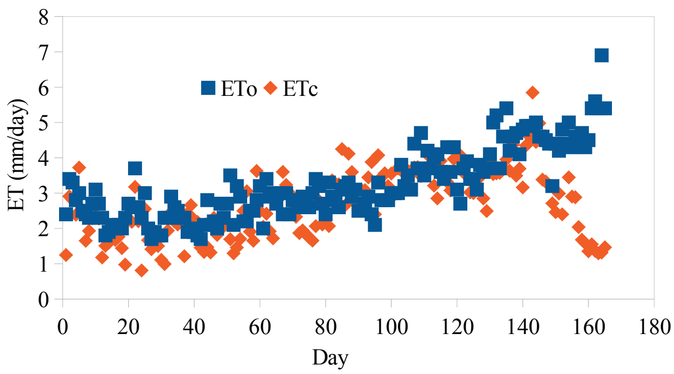

Figure 9: Estimated ETc for the barley (28 Nov 2011 - 10 May 2012).

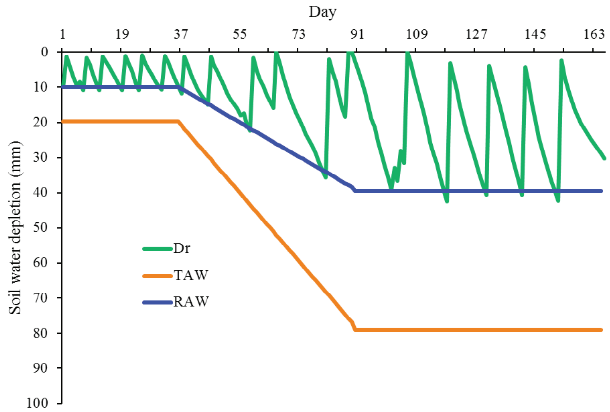

Figure 10: Estimated daily soil water depletion for barley under full irrigation treatment (FI).

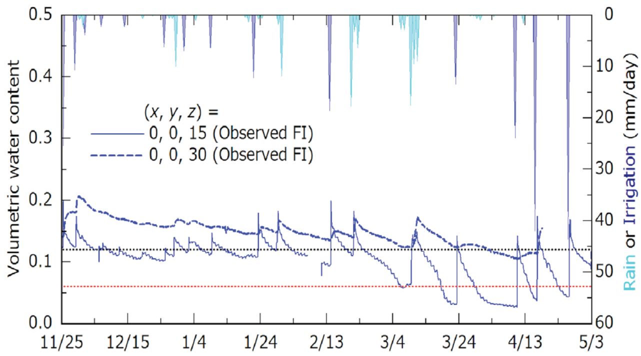

Figure 11: Changes in observed volumetric water content (VWC) at a depth of 15 and 30 cm below the lateral drip line in the FI treatment.

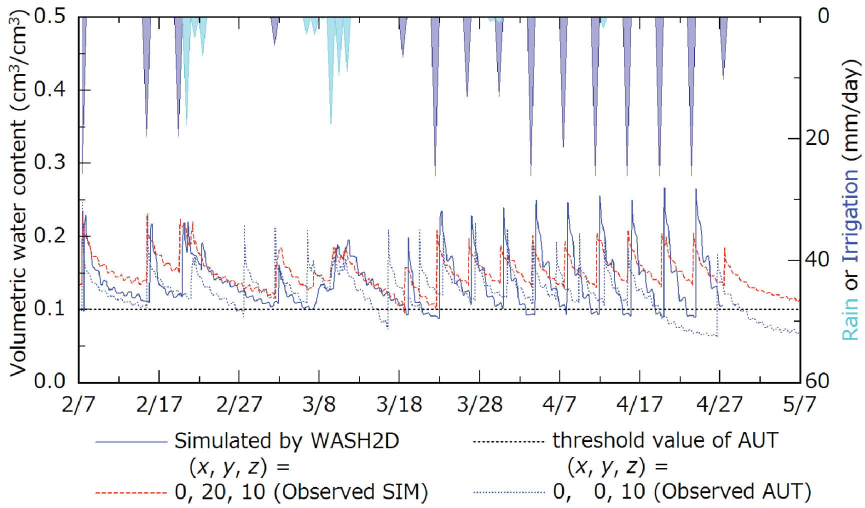

Figure 12: Comparison of observed and simulated water content at a depth of 10 cm below the lateral drip line in the simulated and automatic treatments.

3. Results and discussions

3.1. Full and deficit irrigation: FI, DI70, DI50, DIM50

3.1.1. Climatic conditions: Daily maximum and minimum temperature, and wind velocity (Figure 6 and 7) were obtained from the meteorological weather station in IRA to compute crop coefficient curves. Figure 8 shows the calculated Kc (KsKcb+Ke) during the growing period of barley. The potential Kc value during the barley growing season was about 1.15 to 1.3 following rain or irrigation events when the soil surface layer was wet. The Ke spikes represent increased evaporation when irrigation or precipitation wetted the soil surface and temporarily increased ETc values. The evaporation spikes were lower during the initial portion of the growing period since only fraction of the soil surface (*fw*=0.5) was wetted by irrigation. The wet soil evaporation spikes decrease as the soil surface layer dries out the value of Ke became zero during the growing periods when the soil surface was dried.

3.1.2. Estimation of evapotranspiration: Figure 9 illustrates the changes in daily ET_c relative to ET_0 for the barley crop. During the first 36 days after planting, most of the crop evapotranspiration consisted of soil evaporation, controlled mainly by soil hydraulic properties and solar radiation. The mean ET_c value was about 1.96 mm/day.. As the crop canopy grew, ET_c increased and reached a mean value of 3.46 mm/day at mid-season (92-134 days after planting) and of 3.06 mm/day at late season stages (135-165 days after planting). At the late stage, where the canopy senescence began, the high ETc values were principally attributed to the soil evaporation induced by the frequency of irrigation or precipitation and also to the high evaporative demand.

3.1.3. Soil water depletion: Figure 10 illustrates soil water depletion, estimated by the spreadsheet program, during the cropping period including the occurrence of precipitation and irrigation. It illustrates also the effect of increasing readily available water in the root zone. The rate of root zone depletion at a particular moment in the season is given by the net irrigation requirement for that period. Each time the irrigation water is applied, the root zone is replenished to the field capacity.

3.2. Soil water content

Figure 11 shows the changes in observed volumetric water content (VWC) at a depth of 15 and 30 cm below the lateral drip line in the FI treatment. Topside x-axis shows the rain (aqua) and irrigation amounts (blue).VWC at a depth of 15 cm (blue line) declined to the wilting point in the beginning of March and a few times below in the middle of March. It is thought that barley in the FI treatment had a drought stress during this period. Hence, it is also thought that the barley in the DI70, DI50 and DIM50 treatments had also drought stress during this period because irrigation amount in these treatments was lower than in the FI treatment. Figure 12 shows the comparison of observed and simulated water content at a depth of 10 cm below the lateral drip line in the simulated and automatic treatments. The result shows that VWC simulated with WASH_2D (blue line) could agree well with the observed one (red dashed line). Additionally, it is thought that VWC in the automatic and simulated treatments on the growing season was more than 0.10, so that the barley in these treatments was not affected by any drought stress.

3.3. Soil salinity

Figure 13 shows the changes in soil salinity (ECe) of 0 – 20 cm depth under the FI, DI70, DI50 and DIM50 treatments. The difference among the treatments was small, around 13 February ECe decreased due to low evapotranspiration and rain. Previous study has shown that a 10% yield reduction of barley could occur as a result of salinity stress when the ECe is more than 10.0 dS/m (Ayers and Westcot 1985). Based on this ECe threshold, the barley in these treatments had only small salinity stress during the growing season. In other words, the difference in yield among the treatments was based on the difference in VWC rather than that in salinity.

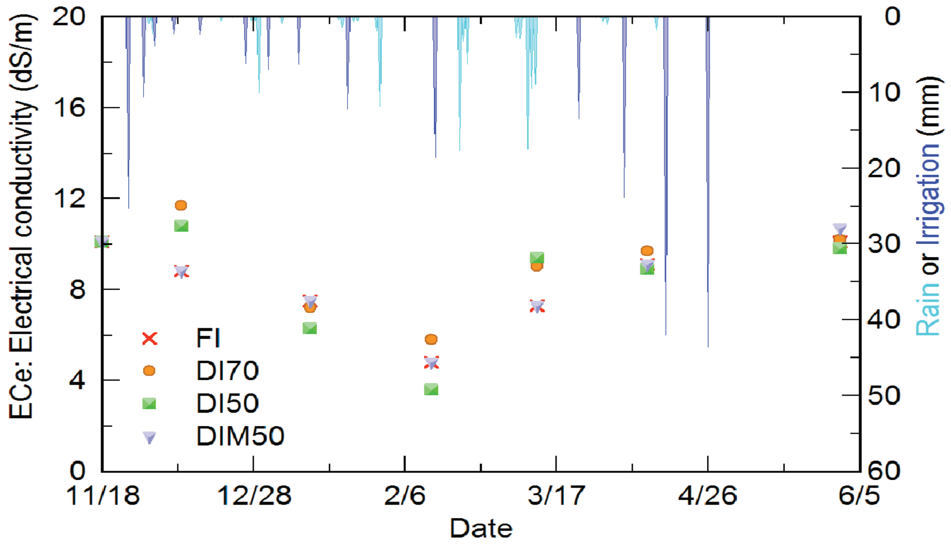

Figure 13: The changes in soil salinity of 0 - 20 cm depth under different irrigation treatments.

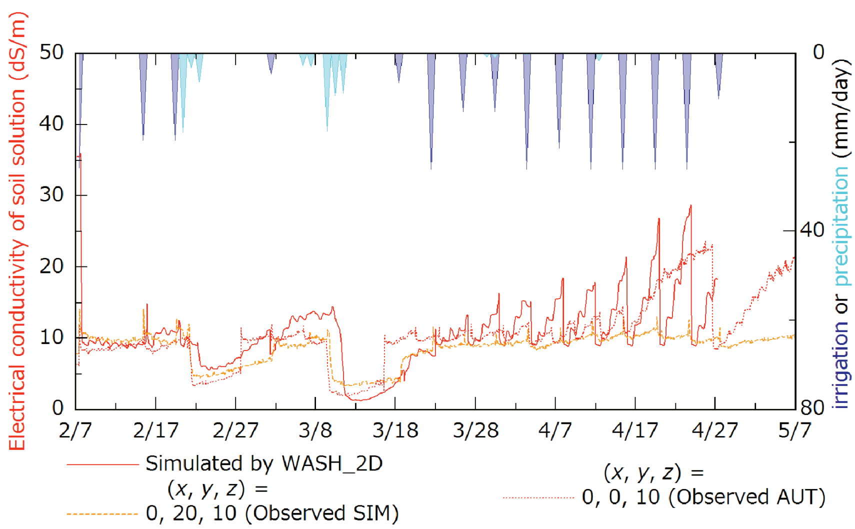

Figure 14: Comparison of observed and simulated electrical conductivity of soil solution at the depth of 10 cm below the lateral in the simulated and automatic treatments.

Figure 14 shows the comparison of observed and simulated electrical conductivity (EC) of soil solution at a depth of 10 cm below the lateral drip line in the simulated and automatic treatments. On April there was a difference in EC between simulated with WASH_2D model (red line) and that of observed (orange dashed line). One of the reasons is that the evapotranspiration simulated with WASH_2D might have been overestimated in this period. In addition, the soil in this study includes some gypsum which is insoluble salt that may have an impact on the measurement.

3.4. Yield and water supply

Data on the amount of applied irrigation water under different irrigation treatments during the growing period are presented in Table 2. In the automatic irrigation treatment, the irrigation amount of 547.7 mm, which was the highest, was applied. While in the simulated treatment, irrigation amount of 513.8 mm was applied, which was lower than the automatic treatment to maximize net income, however it was much higher than that of the FI, DI70, DI50 and DIM50 treatments.Assumed water price used in WASH_2D was lower than the actual. In other words, it was assumed that net income would be gained more than the actual, and simulated irrigation was applied. If this assumption was not performed, using the simulated irrigation treatment could further reduce the irrigation amount.

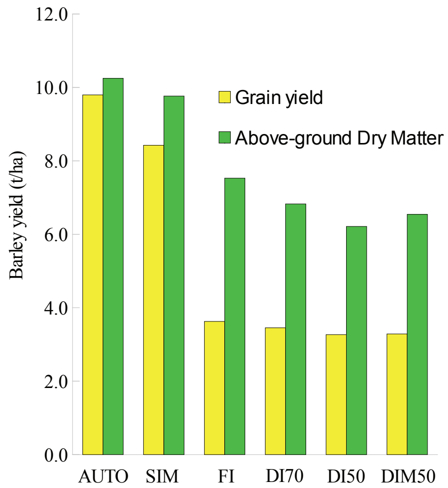

Figure 15: Grain yield and dry matter of aerial part under different irrigation.

Table 2: Water supplies under different irrigation treatments

	Irrigation (mm)	Precipitation (mm)	Total water supply (mm)
AUT	547.7	105.6	653.3
SIM	513.8	105.6	619.4
FI	217.2	105.6	322.8
DI70	164.7	105.6	270.3
DI50	126.6	105.6	232.2
DIM50	174.5	105.6	280.1

Figure 15 shows grain yield and above-ground dry matter under different irrigation treatment. Maximum grain yield and dry matter observed in the automatic treatment, whereas the minimum occurred in DI50. In the FI, DI70, DI50 and DIM50, the crop developed higher above-ground dry matter than grain yield. On the other hand, in the automatic and simulated treatments above-ground dry matter development and grain yield production were similar. It is thought that the difference of irrigation amount among the treatments may have made this difference.

3.5. Water use efficiency

Figure 16 shows water use efficiency under different irrigation treatments. Application of DI50 could get the highest WUE. Therefore, it is recommended in the region where water is considerably limited. Adopting DI50 has a beneficial effect on the water resources in the arid region by decreasing irrigation amount.

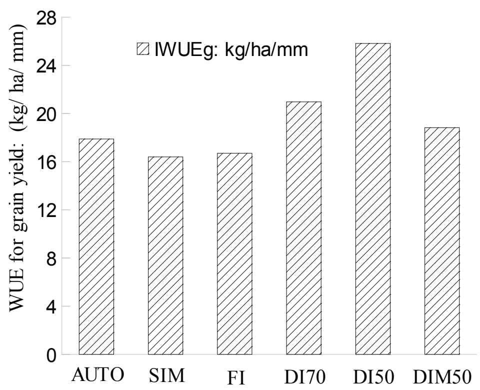

Figure 16: Water use efficiency under different irrigation treatments.

3.6. Net income

Where water resources are relatively abundant and water price (Pw) is low (0.000015 \$/kg), which was assumed in this experiment for the simulated treatment, the difference of net income among the treatments is shown in Figure 17a. The barley price is 0.2615 \$/kg. In this case, the simulated treatment increased the net income through increasing the irrigation amount applied due to low water price. When water resources are more limited than Figure 21a and Pw is twenty times (0.0003 \$/kg) of that given in Figure 17a, the net income would be changed to Figure 17b. In this result, the automatic treatment represents the highest net income. If the water is considerably limited and the Pw is twice (0.0006 \$/kg) as the one assumed in Figure 17b, only DI50 can get a positive net income as shown in Figure 17c.

4. Conclusion

If the water price is low, net income equivalent to the automatic treatment could be gained in the simulated treatment. The farmers who can increase water use have the potential to get more net income through increasing the irrigation amount. This method would be recommended in

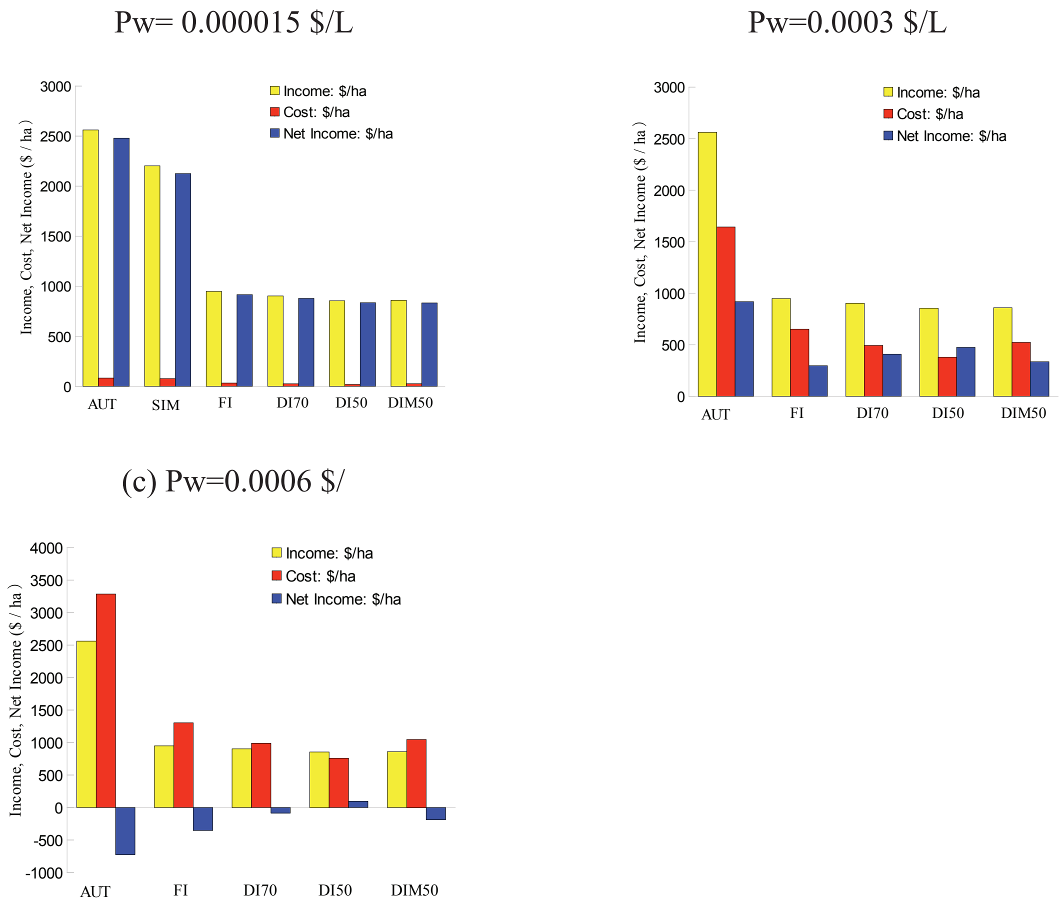

Figure 17: Net income based on grain yield under different irrigation treatments, at water price (Pw) of (a) top: 0.000015 $/Liter; (b) middle: 0.0003 $/Liter; and (c) bottom: 0.0006 $/ Liter.

the area where relatively abundant irrigation water can be applied. On the other hand, deficit irrigation such as the DI50 treatment can be adopted to increase water use efficiency and save water. In that case, the farmers can apply surplus irrigation water to an additional field and may increase net income. Such a method would be recommended when water is considerably limited.

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Improved on-farm irrigation management for olive growing

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Abstract

The key success factors of the olive oil market are the enhancement and stabilization of olive yields, improvement of olive oil quality and reduction of production costs. There is great potential for water saving in olive production in Morocco and Syria. The main purpose of this four year (2010-2014) study is to enhance crop yields of smallholder olive farmers in two Mediterranean countries - Morocco and Syria, through the optimization of water management practices applied to olive cultivation. Due to the sufficiency of rainfall in Syria for growing olives, the study investigates the effect of supplemental irrigation in increasing and stabilizing yield, whereas in Morocco the low rainfall allows only irrigated olive cultivation and so the study investigates the effects of deficit irrigation in reducing water consumption without adversely affecting the olive yield. Results indicate that adding 230 mm (@ 100% of crop water requirement) supplemental irrigation led to as much as 175% increase in olive yields in Syria, and in Morocco, adding water at 70% of ET_c led to 63-77% saving in water compared to flood irrigation along with 13-43% increase in yield.

Introduction

Olive has been cultivated since the beginning of historical times in its native Asia Minor. Its cultivation spread very early to most of the Mediterranean countries and this is still the prime area of production since this crop requires very warm average temperatures, dry climates and does not tolerate cold climatic conditions. The key success factors of the olive oil market are the enhancement and stabilization of olive yields, improvement of olive oil quality and reduction of production costs.

The main purpose of this four year (2010-2014) study is to enhance crop yields of smallholder olive farmers in two Mediterranean countries - Morocco and Syria, through the optimization of water management practices applied to olive cultivation. Improved and more stable olive yields are going to lead to improved earnings and livelihoods for the targeted smallholder farmers. The project objective is achieved through the demonstration and dissemination of sustainable irrigation technologies, water management practices and effective irrigation techniques. Pilot demonstration fields were set up in each country (Tessaout research stations near Marrakesh, Morocco and Dara'a research stations and farmer's field in Syria, Fig. 1) in predominantly olive-growing areas with diverse soil and climatic conditions, where rainfed or traditional irrigation methods now prevail. The study is transferring best practices and know-how to farmers on irrigation, fertilization and pest control through the management of the pilot demonstration fields and systematic training sessions. Secondary beneficiaries are local researchers and extension officers who benefit from intensive training.

Figure 1: Location of study sites in Morocco and Syria.

Materials and methods

Syria

In Syria, since the rainfall of 300-400 mm in olive growing regions is sufficient for rainfed production, the study investigates adoption of supplemental drip irrigation to substantially increase the olive productivity. There are two sites where research on supplemental irrigation is carried out – Al Ash'ari farmer's field and a research station – both located in Dara'a. Another site was initially selected and characterized in Sarbaya, near Aleppo, but due to civil unrest and poor security in the area, the research at this site had to be discontinued after July, 2011.

Al Asha'ari farmer's field site: The site belongs to a private farmer from Dara'a countryside. The average rainfall here is 324 mm. Experiment here includes three water treatments: 100% of CWR (crop water requirement), 50% of CWR, and rainfed treatment (control). The trees are on-average 46 years old and are spaced at 10 m x 10 m distance (Fig. 2). Drip irrigation systems are at 8 drippers/tree for the 100% of CWR treatment and at 4 drippers/tree for the 50% of CWR treatment, with a discharge of 16 L/hr./dripper, where the irrigation time for the two treatments is equal. Fertigation operation is performed using a Dosatron-type fertilizer injector. Two fertilizer management practices were performed in February, 2012 and all recommended amounts of phosphorus and potassium (300/kg/ha) fertilizers were added. For nitrogen, 50% of the total amount (300/kg/ha) was added before cultivation, while second half was added by applying fertigation during the season. As for soluble fertilizers (N, P, K), elements, an amount of 100/kg/ha was added during the season; calculation of the amounts of fertilizers depended on soil analyses. 'Sorani' cv. of olive was grown at this site.

Jillin Agricultural Research Station site: Jillin agricultural research station belongs to General Commission for Scientific Agricultural Research (GCSAR). It is located 25 km north of Dara'a City, with an annual rainfall average of 400 mm. Experiment includes three water treatments: 100% of CWR, 50% of crop water requirement, rainfed treatment (control). Trees are on average 30 years old and are spaced at 8 x 8 m distance (Fig 3).

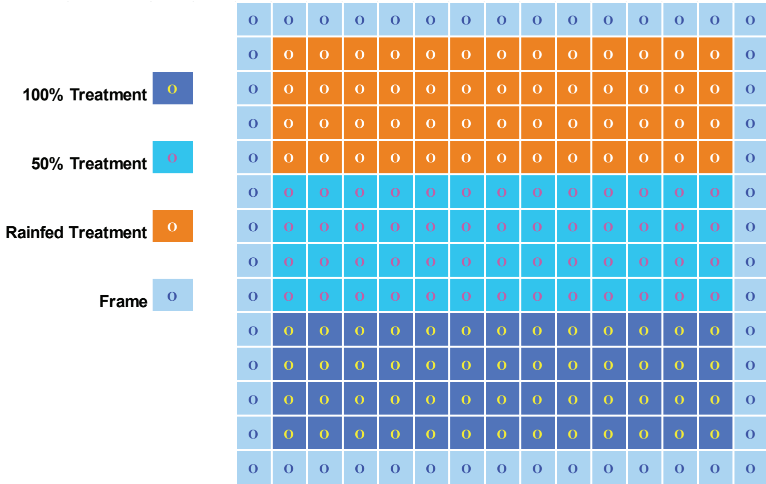


Figure 2: Experimental design – Al Asha'ari farmer's field in Dara'a Province, Syria.

Drip system with 8 drippers/tree for the 100% CWR treatment and 4 drippers/tree for 50% CWR treatment, and a discharge of 16 L/hr/dripper, were installed where the irrigation time for the 100% and 50% CWR treatment was equal. Fertilizer application was the same as at the farmer's field.' Sorani' and 'Jluott' cultivars of olive were grown at this site.

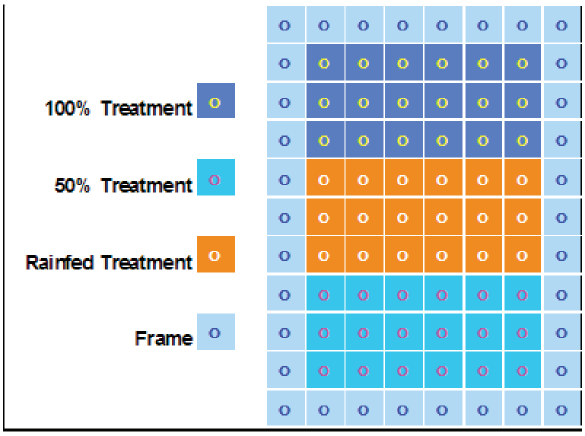


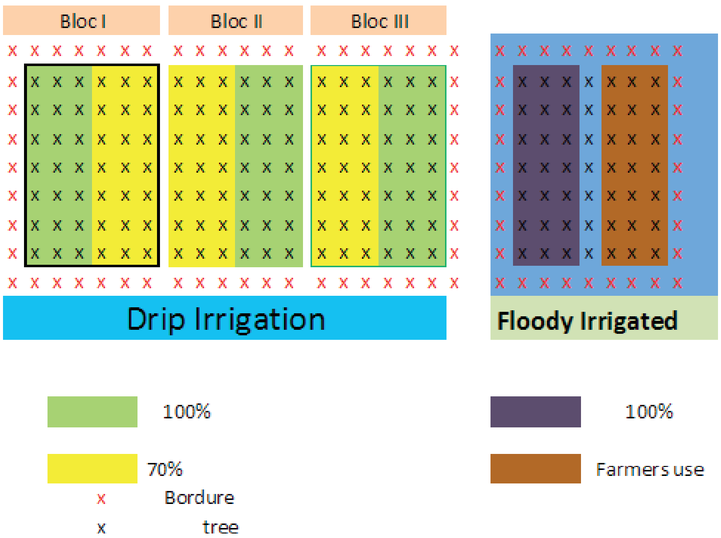
Figure 3: Experimental design –agricultural research station, Dara'a, Syria.

Morocco

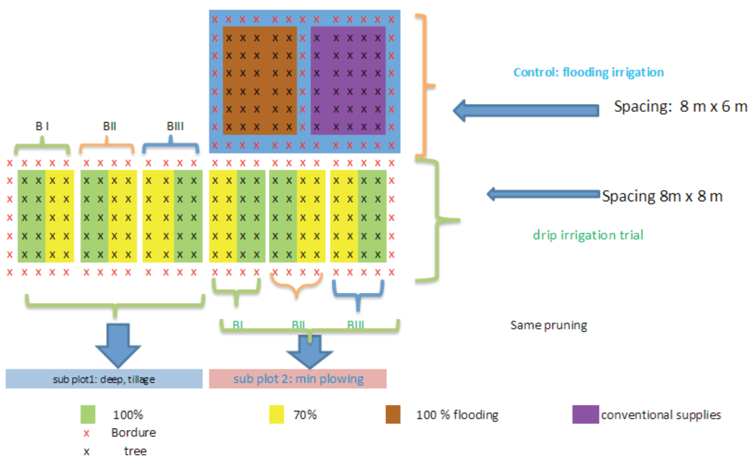
Two irrigation methods were used, drip irrigation with two water regimes and flood irrigation or traditional system used by most of the farmers. The planting density of the orchard was 208 trees ha^{-1} in the case of flood treatment with a row spacing of 8 m x 6 m and 156 trees ha^{-1} for drip irrigation treatment with 8 m x 8 m row spacing. In both systems, olive trees had the same age.

Drip irrigation and traditional irrigation systems are used in two adjacent plots. A randomized complete block design (RCBD) is used with three replications per irrigation regime in the case of drip irrigation system (Fig. 4). The drip irrigation plot had an area of 1 ha and the traditional irrigation plot had an area of 0.5 ha. The drip irrigation experimental plot included 6 subplots (two irrigation regimes x three replicates). The two irrigation regimes under drip irrigation systems wre: 100% of crop evapotranspiration (ET_c) and 70% of ET_c. Each replicate included 10 trees. Deep tillage was conducted on 13 January, 2011 at 60 cm depth and 1 meter from the trunk. The ET_c was calculated following the equation: $ET_c = ET_o \text{ x } K_c \text{ x } K_e / N_e$

where ET_o is the reference evapotranspiration (Penman Monteith) and K_c is the crop coefficient for olive tree, K_r is the corrector coefficient and N_e is the efficiency of irrigation network.



Saada agricultural research station, Marrakesh, Morocco



Tessaout pilot plot design, Marrakesh, Morocco

Figure 4: Experimental design in Morocco.

Results and discussion

Syria

During 2012 growing season, by applying deficit supplemental irrigation at Dara'a experiment station at 50% ET_c (353 mm rainfall + 162 mm irrigation), fruit yield increased by 2,460 (33%) to 3,900 (96%) kg/ha (Fig. 5) as compared to rainfed plantation. Yield of Sorani cv. was always higher than Jlout cv. at all locations. The water productivity (WP) ranged between 1.1 and 2.1 kg/m^3 ET. There was a further increase of 1,250 (13%) to 2,030 (25%) kg/ha by switching from 50% ET_c to 100% ET_c. The lowest WP was found for rainfed Sorani cv. at farmer's field (not shown here) and highest for rainfed Sorani cv. at experimental station in Dara'a, but yields were always higher for irrigated olives plantations compared to rainfed proving that there is a loss of yield if we do not irrigate. In terms of percentage oil extracted from fruit, Sorani cv. grown under 50% ET_c treatment produced highest values (24%).

Similar results were found during 2011 growing season (not shown here) – yields increased by as much as 113% (4,375 kg/ha vs. 9,360 kg/ha) when 115 mm of irrigation was applied (in addition to 316 mm rainfall) by drip. A further increase of 2,652 kg/ha (28%) was achieved by applying 115 mm of irrigation (100% ET_c) in addition to the rainfall.

Morocco

In Morocco, the rainfall in olive growing regions is low (200-250 mm) and insufficient to grow olives using just the rainwater. So, farmers are compelled to practice irrigated olive plantations, mostly using the flood method. Our research compares traditional flood irrigation method with drip irrigation applied at full and regulated deficit level. Our results indicate that by adopting improved irrigation methods, there was a gain in yield of fruit and oil, and water productivity increased significantly, thus, saving water and increasing farmers' income. There was a declining trend with total water applied for all the four parameters. The linear trend was found significant ($P<0.05$) for oil WP.

During 2011 growing season (a relatively wetter than normal year - 303mm) at experiment site in Marrakesh, by switching from traditional flood irrigation to drip irrigation, there was a saving of 66% of water (600 mm vs. 203 mm), 27% increase in olive fruit yield, 76% increase in water productivity (0.19 kg/m^3 vs. 0.78 kg/m^3) and 31% increase in oil yield (Fig. 6). Another 11% saving of water was possible by applying deficit drip irrigation at 70% of ET_c level - yield was 13% higher than traditional irrigation method, water productivity was 80% higher and oil yield was 25% higher.

Figure 6: Comparison of 2011 growing season olive fruit and oil yield, water applied and water productivity between flood and drip irrigation (at 100% and 70% ET_c) treatments at Tessaout experiment station in Marrakesh, Morocco.

The 2012 growing season received less than normal rainfall (140 mm) and so the water requirement of olive trees, in addition to the rainfall, was higher than the previous year (not shown here). Traditional flood irrigation method consumed 1,061 mm of irrigation water and produced 4,530 kg/ha olive fruit yield with a WP of 0.43 kg/m^3 ET. Switching to regulated drip irrigation reduced

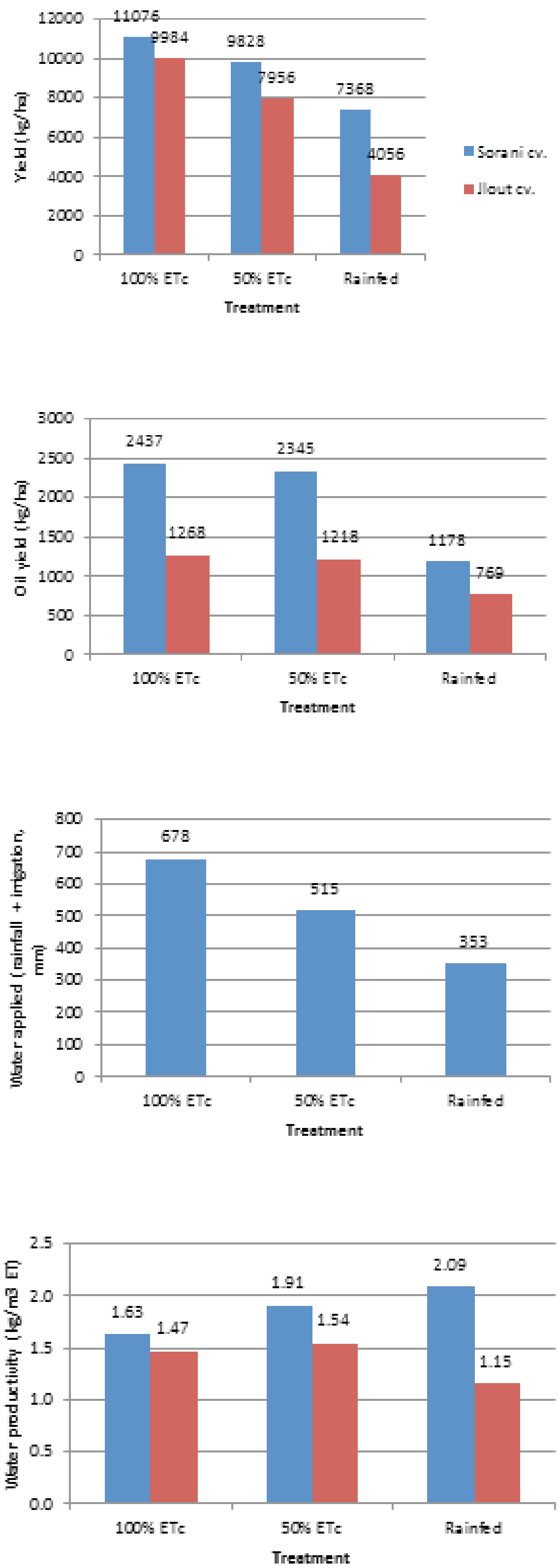


Figure 5: Comparison of 2012 growing season olive fruit and oil yield, water applied and water productivity between rainfed and drip irrigation (at 100% and 50% ET_c) treatments for Sorani cv. and Jlout cv. at experiment station in Dara'a Province, Syria.

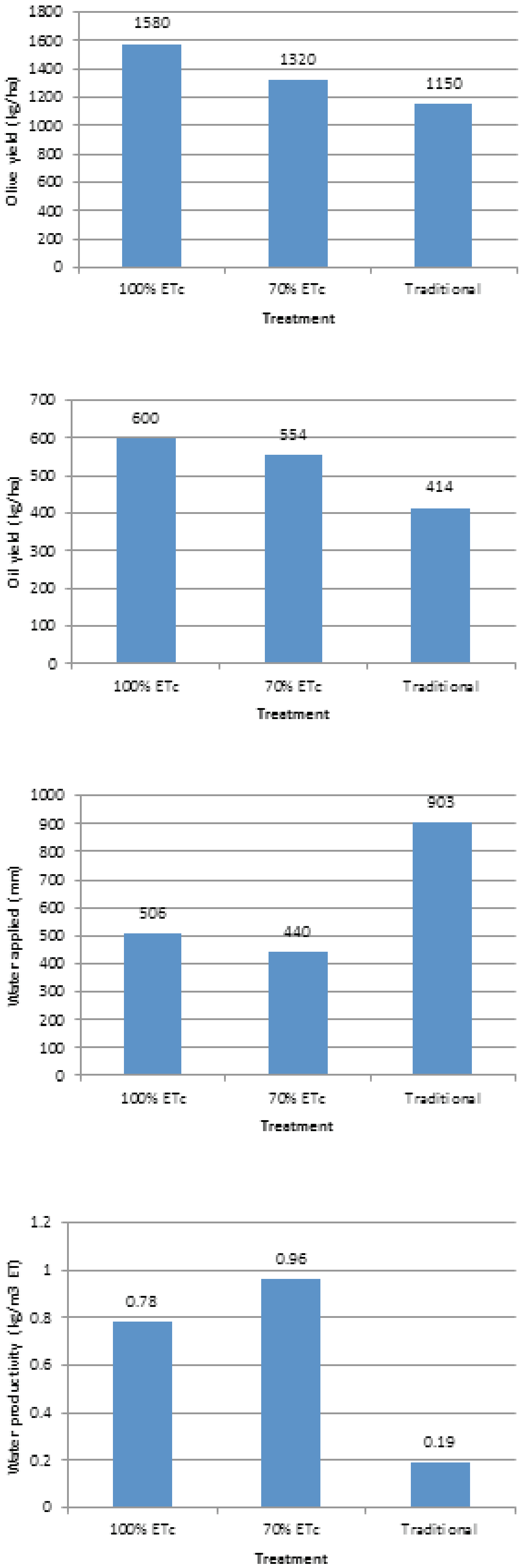


Figure 6: Comparison of 2011 growing season olive fruit and oil yield, water applied and water productivity between flood and drip irrigation (at 100% and 70% ETc) treatments at Tessaout experiment station in Marrakesh, Morocco.

the water usage by 412 mm (39%) for 100% ET_c treatment along with an increase of 3,040 kg/ha of yield (40%), and 70% ET_c treatment further saved 157 mm water (24%) and further increased yield by 190 kg/ha (2.5%).

Statistical analyses

Using the three and higher factor interaction of year, location, irrigation and cultivar as experimental errors, their main effects and two factor interactions were evaluated using the restricted maximum likelihood method for analysis of unbalanced data. The two factor interactions when found insignificant ($P>0.05$) were also merged into experimental errors. The effects and interactions that were found statistically significant ($P <0.05$) included: irrigation treatments and cultivars for yield and oil, and their interaction for oil. For yield and oil water-productivities, cultivar differences were significant.

Conclusions

The results from two years' of research suggest that applying small amount of water by drip irrigation, in addition to rainfall, can be beneficial in two ways – it helps increase the yields of fruits as well as oil, and it helps stabilize the yields.

We have two more seasons of field research remaining to complete. We are simultaneously starting to put in more efforts towards dissemination of the knowledge being generated by the project through informational videos, interviews with the scientific team members, posters, documentation of success stories, conduct of farmer field days, oil tasting sessions, visit to the fields by media persons and decision makers, development of project website etc. The study shall conclude in November, 2014 with a regional conference of olive growing countries and shall target the agricultural extension, academic, scientific and policy- and decision-making communities.

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Stress irrigation in fruit growing in the semi-arid region of Dobrogea, Romania

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Abstract

The risk of aridity is spreading in Romania, especially in its southeastern region, e.g. in the semi-arid region of Dobrogea where most of the crops have to be irrigated during summer time. The above region is characterized by annual average temperature between 10.0 and 11.5 ˚C, precipitation 325 – 465 mm, Penman-Monteith reference evapotranspiration of 750 to 820 mm, water deficits between -320 and -420 mm, aridity indexes: De Martonne aridity index ($I_{ar\text{-}DM}$) between 0.15 and 0.22 (mm/˚C), UNESCO 1979 aridity index ($I_{ar,\ P/ETo}$) with values between 0.45 and 0.55 (mm/mm). However, water resources are limited and there is competition for water use and energy during summer time when irrigation application is required. Consequently, to save water, deficit irrigation techniques should be developed and employed in general in agriculture, and particularly in orchards. This paper deals with experimental data obtained in the most representative fruit trees of this region, i.e. peach and apricot, and proposes irrigation methods and technologies to achieve this goal.

Introduction

More frequently than ever before, scientists now speak about aridity and climate change on the international scale. There are various opinions and scenarios worldwide on global warming. For instance, Peterson and Baringer (2009a and 2009b) have reported that global warming is only a hypothesis, and the increase in temperature in recent years is controversial, arguing that the global temperature did not rise in the past decade. Knight *et al.* (2009) documented that for the January 1999 - December 2008 period the HadCRUT3 dataset showed a temperature change of only +0.07 $\pm$ 0.07 ^{o}C/decade. Notwithstanding the above, regionally or locally, i.e. in Romania (Marica and Busuioc 2004; Sandu and Mateescu 2009; Sandu *et al.* 2010, Busuioc *et al.* 2010) the temperature increased recently and aridity would rise especially during the crop growing season in the southern parts of this country. A similar opinion was expressed by Paltineanu *et al.* (2011a, 2012a) who showed that as a consequence of temperature rising, reference evapotranspiration (ETo) and crops evapotranspiration (ETc) as well as irrigation water requirements (IWRs) increased in the first decade of the 21th century versus the past century in the southern part of this country, combined with a time redistribution of these changes during the year. Other studies report that for the future decades, in spite of a probable increase in temperature, reference evapotranspiration and irrigation water requirements would not increase due to increasing air humidity and higher CO_2 concentrations, which both tend to reduce transpiration and counteract the higher temperature effects on ETo (Snyder 2011, 2012).

Arid and semi-arid regions are spread over a large surface area on the global scale, but these are differently defined depending on author. Aridity can be expressed in various ways, using reference evapotranspiration (ETo) and precipitation (*P*) as aridity indexes, e.g. as *P/ETo* ratio (*UNESCO aridity index, 1979), or as the difference between the two factors from above (*P - ETo*) resulting in the climatic water deficit (*WD*) (Paltineanu *et al.* 2007b). Maliva and Missimer (2012) have recently reviewed and described aridity through various aridity indexes applying worldwide.

Various irrigation scheduling methods in orchards have been studied to optimize water application to fruit trees. One is use of the crop water stress index (CWSI, Idso *et al.* 1981). Measurements of canopy temperature and calculation of CWSI were shown to be valuable in irrigation scheduling by Jackson *et al.* (1981). In the same context, Paltineanu *et al.* (2005, 2007a and b, 2009a) have also reported data on arid or drought-affected areas, including water-crop response and *IWRs* for various regions of Romania. In other recent papers, Paltineanu *et al.* (2011b, 2011c and 2012b) have studied CWSI in apple and peach in this country and have found critical values for irrigation application scheduling, and also reported data on yield and irrigation efficiency under water stress conditions for peach and apricot.

Peach (*Prunus persica* (L) *Batsch*) and apricot (*Prunus armeniaca* L.) are among the most widely cultivated temperate climate fruit-trees in Romania. The purpose of this paper is to study the average situation concerning climate and crop water requirements in the semi-arid region of Dobrogea, Romania, and to show new ways of irrigation application under water stress conditions in growing peach.

Materials and method

Climate parameters and conditions

Mean monthly and annual weather statistics were calculated for 17 weather stations and 51 pluviometric centers located in the south-eastern part of Romania, i.e. Dobrogea, between northern latitudes of 43º43' and 45º26' and eastern longitudes of 27º17' and 29º41'(Fig. 1).

Most of Dobrogea Plateau region is at 100 and 300 m altitude. It is the most arid region of this country. The climatic data consisted of mean temperature and precipitation, as well as other climatic parameters needed in calculating the FAO recommended Penman-Monteith reference evapotranspiration (*ETo*) like: sunshine hours, air humidity, as well as wind speed at 2m height (Allen *et al.* 1998). The period of investigation was between 1960 and 2010. The quality of data set was reliable being recorded in the national network, and standard quality control methods were applied to the data set used.

Penman-Monteith ETo was calculated as per Allen et al. (1998), whereas the climatic water deficit (WD) was calculated as follows, using monthly sum of precipitation data:

$$WD = P - ETo \quad (1)$$

where: P is the precipitation sum (mm) and ETo is the Penman-Monteith reference evapotranspiration (mm), which was calculated using the combined equation based on daily data of mean temperature, sunshine duration, air humidity and wind speed at 2-m height:

$$ETo = (0.408D(Rn-G)+900gU(ea-ed) / (T+273)) / (D+g(1+0.34U)) \quad (2)$$

where: Rn is the net radiation at grass surface (MJ m^{-2} d^{-1}), G is the soil heat flux (MJm^{-2} d^{-1}), T is average temperature (°C), U is wind speed at 2m height (m s^{-1}), (ea-ed) is vapour pressure deficit (kPa), D is slope of the vapour pressure curve (kPa °C^{-1}), g is psychrometric constant (kPa °C^{-1}). The other terms needed to calculate ETo were taken from Allen et al. (1998) and Jensen et al. (1990).

Crop evapotranspiration (ETc) was estimated by multiplying the ETo values with the Kc values, and irrigation water requirements (IWRs) data resulted from subtracting effective precipitation from ETc (CROPWAT Programme, Smith 1992; 1993), without taking into account the variation in soil water content. The method given by Allen *et al.* (1998) was previously found suitable for Romania conditions by Paltineanu *et al*. (2007b).

Experimental design and irrigation application

The experimental work concerning irrigation was developed at Valu lui Traian, county Constanta, Dobrogea region, about 10 km westwards from the Black Sea coastline, in the 2009 – 2010 period. The peach experiment took place at Valu lui Traian location. The peach cultivar 'Southland' was grafted on franc rootstock, and the 16-year old fruit trees were planted in a 4m x 3m scheme with north-south row orientation. The average tree height is 2.5 m and tree canopy shape is a palmette. The soil management system involved clean cultivation both between tree rows and in the row.

The experiment design was split-plot with three treatments: T1 – fully irrigated according to the irrigation needs calculated (Allen et al. 1998) as described by Paltineanu *et al*. (2007a); irrigation application was carried out when soil moisture content (SMC) was about to reach management allowed deficit (MAD) value, or critical depletion level, which was considered at 50% (the mid-interval between field capacity (FC) and wilting point (WP)); T2 – a stressed treatment irrigated with half the amount of water in T1 and applied almost at the same time as in T1; and T3 – a control, non-irrigated treatment. Each plot consisted of three adjacent fruit tree rows, with the central row containing five trees for measurements and observations.

Sprinkler irrigation has been applied using a 12 m x 18 m grid scheme, a pressure of about 3 bars at the sprinkler nozzle (7 mm in diameter), giving a 7.4 mm h^{-1} application rate as measured in catch cans spaced on a 1m square grid. The Christiansen coefficient of uniformity calculated for irrigation applications was about 85% and showed a relatively good uniformity despite the tree trunks acting as obstacles for the water jets.

Soils and soil moisture content measurements

The soils from Dobrogea region are mainly calcareous chernozems with loamy texture and alkaline pH in topsoil, good soil structure (0-60 cm depth, 1.6-3.0 % g/g humus content, 1.0-10.0 % g/g carbonate content), while in the non-structured subsoil (below 80 cm depth), the humus content is lower than 1% g/g and the carbonates vary from 10 to more 12 % g/g. For the main area of the region land slope ranges between about 2.0 and 5%. Bigger slopes are usually occupied with eroded, less fertile soils.

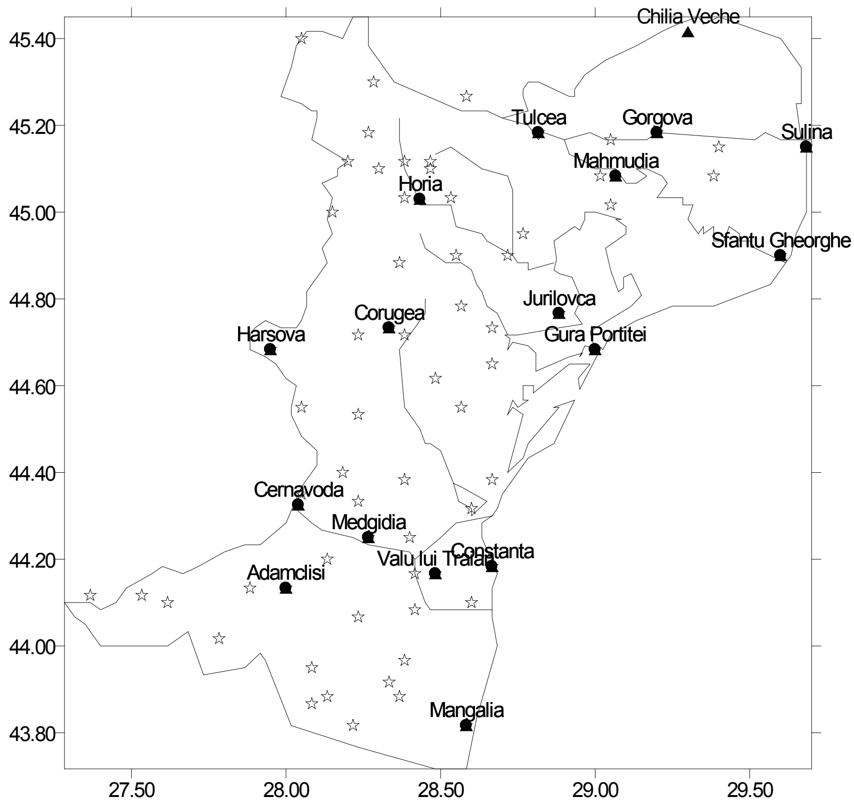

Figure 1: Map of Dobrogea, the south-eastern part of Romania, with 17 weather stations (black signs) providing climate data and 51 pluviometric centers (latitude and longitude are expressed here in the decimal system).

At Valu lui Traian location, soil water potential was measured with Watermark resistance blocks (6450 Watermark Soil Moisture Sensor) installed in two replications per tree at four depths: 20 cm, 40 cm, 60 cm and 80 cm at 1 m distance from the tree trunk. Data were recorded by WatchDog data loggers and downloaded periodically by a laptop. The relationship between soil water potential measured with the Watermark sensors and SMC measured gravimetrically was previously determined from field data (Paltineanu *et al.* 2011b). This field calibration was then applied to the soil water potential readings during the experiment in order to estimate SMC values. In T3, SMC was only measured at some occasions gravimetrically, as its low values were usually out of the range of the sensors. The SMC values were averaged over the main rooting depth of 80 cm, according to the results reported by Indreias (1997), who found a soil active rooting depth of 80-100 cm for peach trees in the region.

Comparisons between the means of variables used in this paper were done by help of SPSS 14 software program.

Results and discussions

Climatic characteristics

The Dobrogea region has a relatively homogeneous climate with respect to temperature. For all 17 weather stations, the dynamics of mean monthly temperature spatially averaged across the region is depicted in Fig. 2. Negative mean temperatures only occur during January. Mean maximum, ranging between 20 and 22 ºC, occur in summer months, and the mean annual temperature reaches as much as 11.0 ºC. Standard deviation (SD) values across the region are small ($\pm$ 0.04%) as is the coefficient of variation (average 3.6%).

Mean monthly precipitation (P) and Penman-Monteith reference evapotranspiration (ETo) values, calculated and spatially averaged for the 17 weather stations across Dobrogea region, are shown in Fig. 3. During the cold season P and ETo are almost equal, with the prevalence of P, and this is the period of the year when the soils accumulate water; during April through October period ETo exceeds P, specifically in summer months, when ETo reaches as much as 123 – 138 mm versus about 40 mm of rainfall. Mean annual P is 396 mm (P ± SD = 358 to 433 mm), while mean annual ETo reaches about 778 mm (P ± SD = 740 to 816 mm). This difference between P and ETo, also called climatic water deficit (WD), exceeds 50 mm per month in most of the growing season, with a maximum in July (-100 mm), Fig. 4. WD accumulates each month and there is no other way to counteract it, except by irrigation application, even if efforts are being made by breeders to create cultivars that should be more resistant to water deficit. On average, annually WD is more than -380 mm spatially distributed across the region, but there are areas especially near the Black Sea coast line with more than -400 mm. However, during droughts of various intensity levels WD gets higher values (absolute values), between -500 and -600 mm/year (Paltineanu *et al.* 2010), resulting a strong competition for water between different economics branches.

Fig. 5 shows mean monthly UNESCO-1979 aridity index (Iar) for all weather stations and their annual average across Dobrogea region. Except for the cold months when Iar values are higher than 1 mm/mm, showing climatic water excess, Iar during the growing season does not exceed 0.5 mm/mm, the threshold for semi-arid character, and in July and August is less than 0.3 mm/mm. The mean annual Iar is 0.5, which shows that Dobrogea is a semi-arid region during the whole year. Among the studied weather stations Iar ranges between 0.45 and 0.55 (mm/mm).

Another method to quantify aridity is the aridity index of De Martonne (1926), as a ratio between precipitation and temperature plus 10ºC, i.e. P/(T+10ºC), which has an annual mean of 18.8 mm/ºC, a SD of 1.9 mm/ºC and a coefficient of variation of 10.2% over the whole Dobrogea territory; actually, De Martonne annual aridity index varies spatially between 0.15 and 0.22 mm/˚C in this region, and this also classifies the region as semi-arid.

Crop water characteristics under no-water stress irrigation

When the groundcover management system is clean cultivation in the orchard, during the growing season ETc for peach and apricot increases continuously from April (about 20-25 mm) to July (120 mm) and August (110 mm); then it decreases in September (60 mm) and October (20 mm), Fig. 6. For the entire growing season ETc reaches as much as 480 mm.

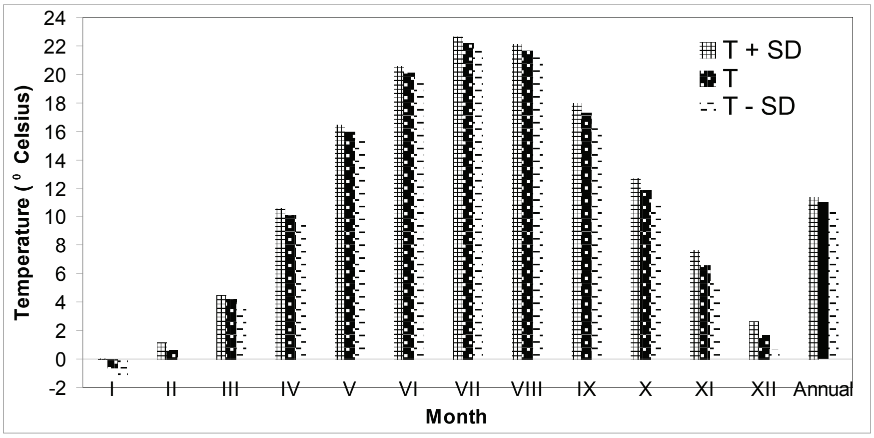

Figure 2: Mean monthly temperatures (T) and their annual average calculated for the 17 weather stations across Dobrogea region, Romania; SD = standard deviations; the shown mean (M) values are between M+SD and M-SD, respectively.

Due to the large climatic water deficits during the period from April through October caused by the sparse precipitation, ETc for these two fruit tree species can be covered by irrigation. Thus, irrigation water requirements (IWRs) for peach and apricot in the case of clean cultivation between tree rows, for all the locations studied across Dobrogea, follows ETc pattern. The first month of irrigation application is May, usually during late May, and particularly during droughts, but on average farmers irrigate in June by applying one irrigation (about 500 m^3/ha), Fig. 6; in July and August together farmers apply about 1500 m^3/ha in three applications, with no more irrigation for the rest of the growing season. The whole IWRs used during an average growing season totals 2000 – 2500 m^3/ha.

When the groundcover management system is represented by mowed sod strips in the orchard, there is a rise in ETc during the growing season for peach and apricot due to the sod water consumption, as shown in Fig. 7. ETc reaches approximately 155 mm in July and 140 mm in August. Annually, the ETc value is 620 mm, about 140 mm higher than in the clean cultivation system.

The average date of irrigation application is also during late May, when there is drought; however, regular irrigation applications are carried out in June with about 700 m^3/ha, (Fig. 7); in July farmers should apply about 1200 m^3/ha and in August 1100 m^3/ha, with no more irrigation for September and October. The whole IWRs used during an average growing season totals 3000 m^3/ha. For extremely droughty years these values could easily exceed 4000 m^3/ha.

Crop water characteristics under water stress irrigation

The best proof showing that there can be alternatives for "fully irrigated" method is the field experiment made "under water stress conditions, or deficit irrigation". Fruit yield and irrigation water use efficiency (IWUE) were considered for this region in evaluating how to save water under the global warming trend. The results depicted in Fig. 8 show that during three years of

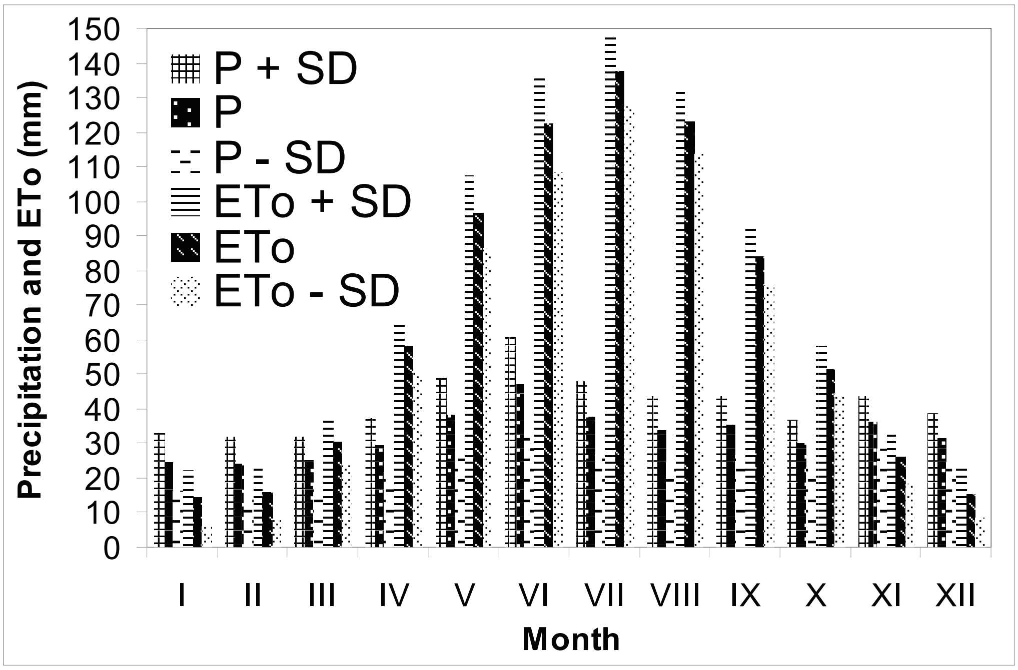

Figure 3: Mean monthly precipitation (P) and Penman-Monteith reference evapotranspiration (ETo) values calculated for the 17 weather stations across Dobrogea region, Romania; SD = standard deviations; the shown mean (M) values are between M+SD and M-SD, respectively.

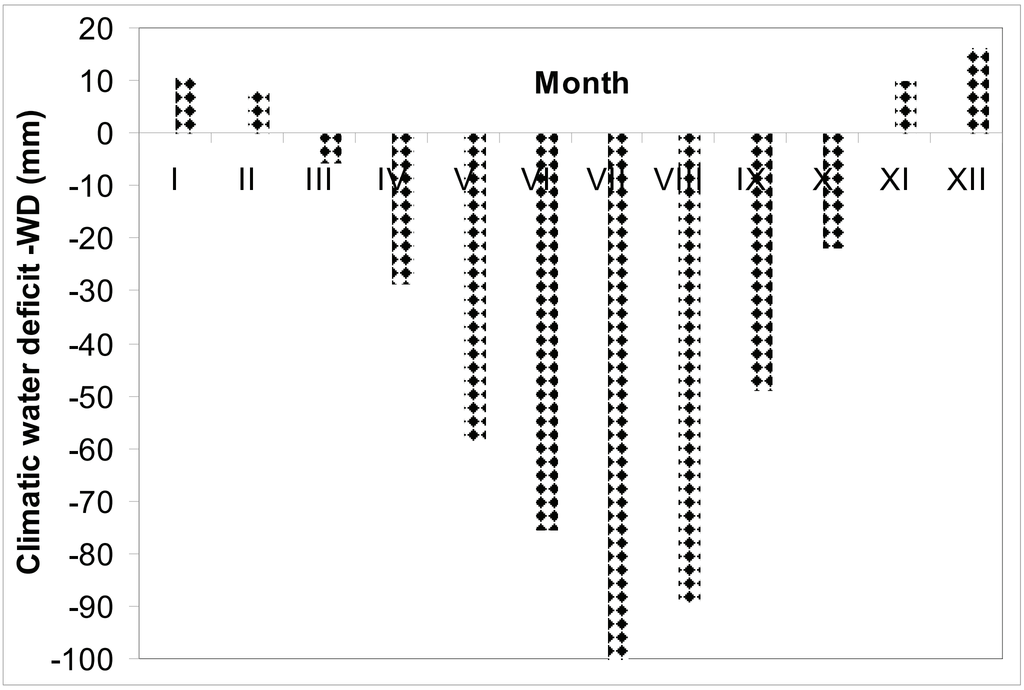

Figure 4: Mean monthly climatic water deficit (WD) values calculated for the 17 weather stations across Dobrogea region, Romania.

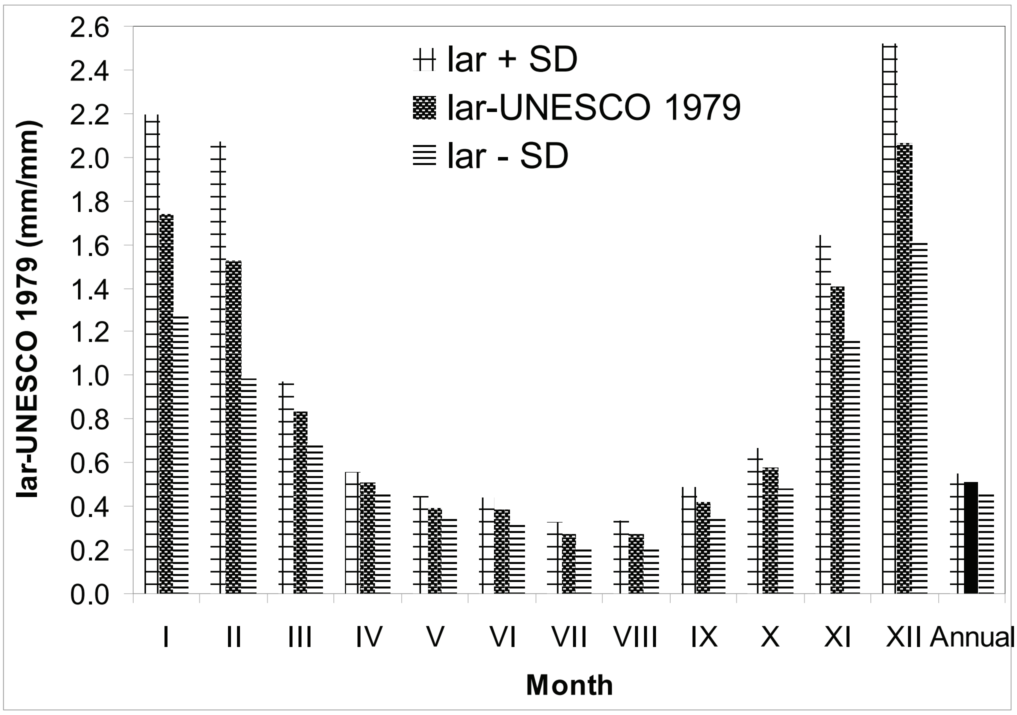

Figure 5: Mean monthly UNESCO 1979 aridity index for the 17 weather stations and their annual average across Dobrogea region, Romania; SD = standard deviations; the shown mean (M) values are between M+SD and M-SD, respectively.

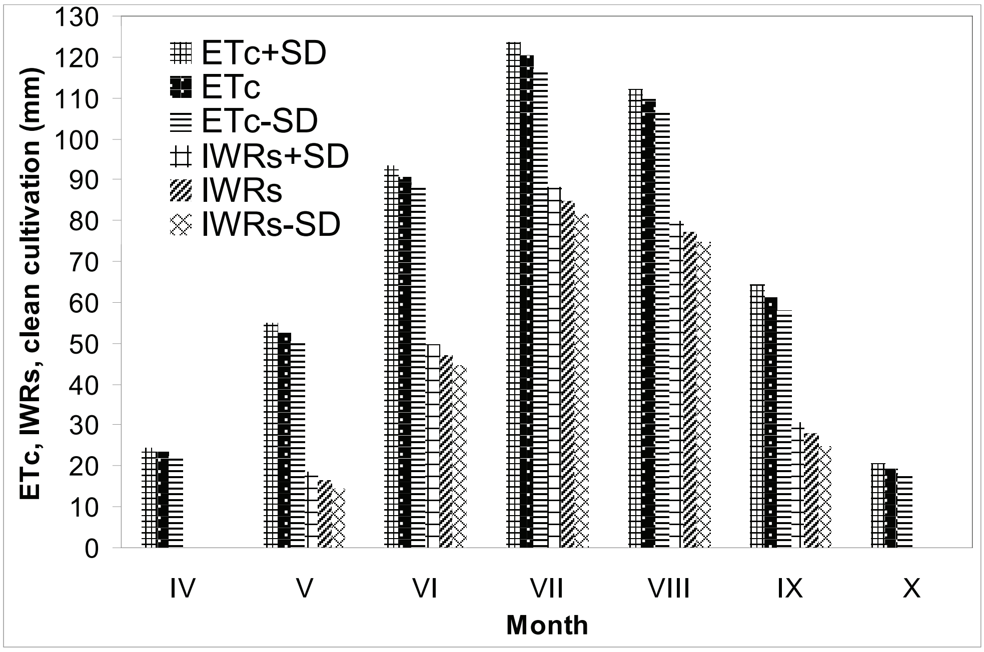

Figure 6: Mean monthly crop evapotranspiration (ETc) and irrigation water requirements (IWRs) for peach and apricot in the case of clean cultivation between tree rows, for the 17 locations studied across Dobrogea region, Romania; SD = standard deviations; the shown mean (M) values are between M+SD and M-SD, respectively.

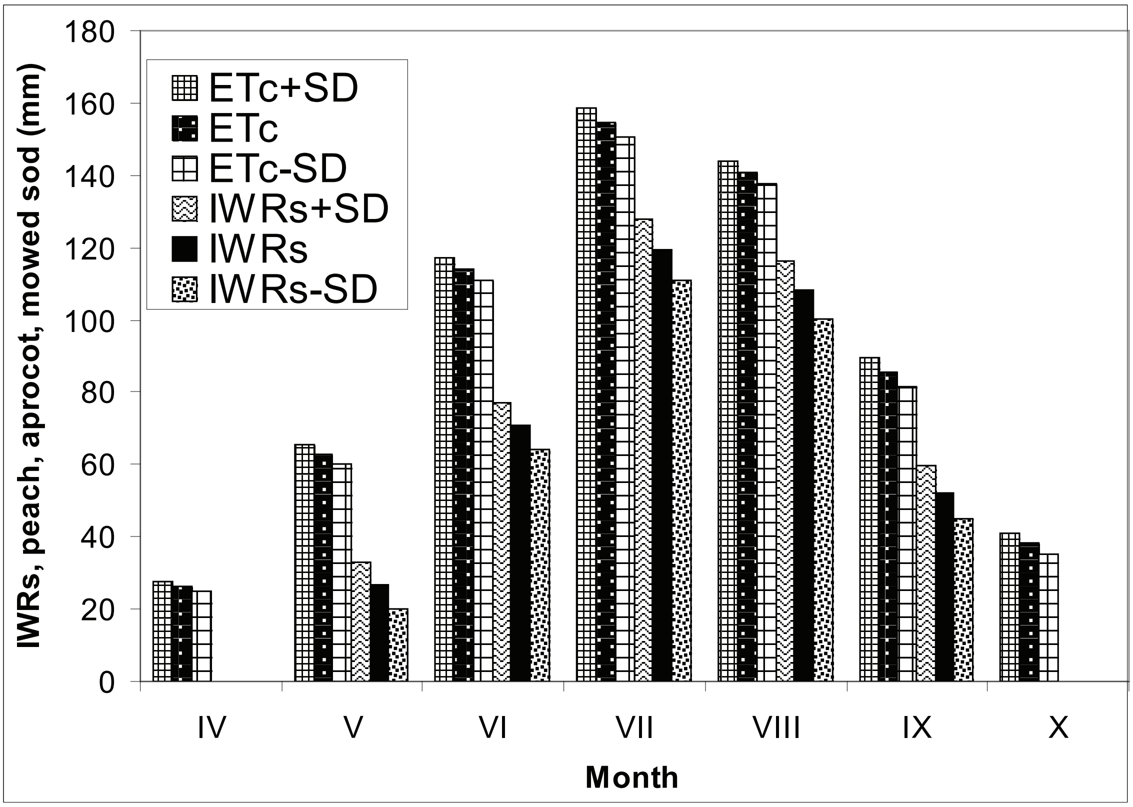

Figure 7: Mean monthly crop evapotranspiration (ETc) and irrigation water requirements (IWRs) for peach and apricot in the case of mowed sod between tree rows, for the 17 locations studied across Dobrogea region, Romania; SD=standard deviations; the shown mean (M) values are between M+SD and M-SD, respectively

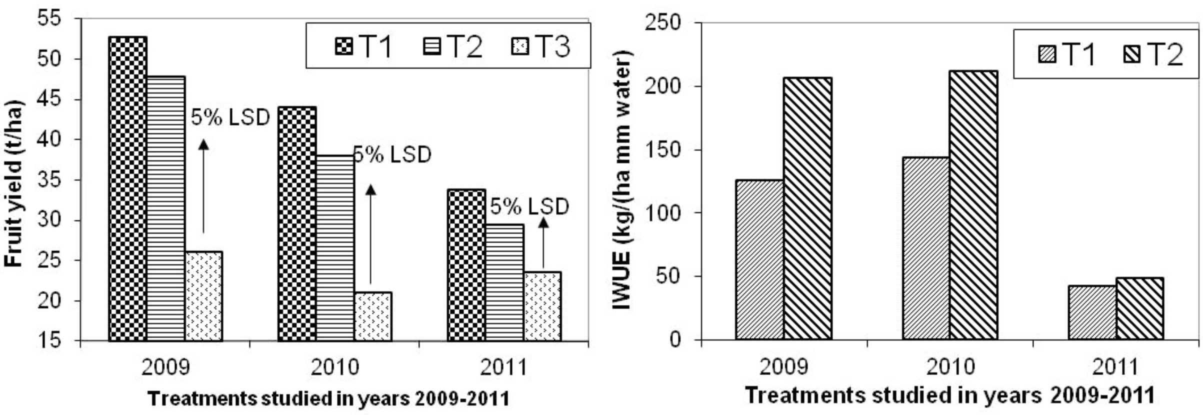

Figure 8: Fruit yield (a) and irrigation water use efficiency (IWUE, b) in the treatments studied T1 – fully irrigated, T2 – irrigated under stress conditions with half the amount of T1, T3 – non-irrigated treatment), 2009-2011, 5% LSD = least significant differences for P< 5%, Valu lui Traian, Dobrogea region.

experimentation (2009 - 2011), there were no significant differences in yield between these two irrigation methods; the fruit yield was usually higher with the fully irrigated treatment, but the water savings could be as much as half the water used in the first case, with low fruit yield losses. Consequently, on average IWUE was higher in treatments under water stress irrigation versus the fully irrigated method.

The 2012 climatic trend at the experimental site

The trend of recent global warming in the region was reported previously, among others, by Paltineanu *et al.* (2009a; 2011a; 2012a). In this respect, for the experimental location of Valu lui Traian, a special attention should be given to the most recent situation from 2012 (Table 1), which compares the mean values of the climate characteristics depicted in Figs. 1 through 5. Thus, from April to October the mean monthly temperature in year 2012 was higher by more than 3ºC (even 4ºC in July and October) than the monthly means, while precipitation was much lower every month except May (with 70 mm excess rainfall); it is to be noted that there was no effective rain during the period from June through October (except the last days), because the rains were lower than 5 mm each. For all the months analyzed here, ETo exceeded the mean monthly values, specifically for the April through July period. The consequences were that WD were very high, exceeding the monthly means by about 36 mm in April, 50 mm in May, 82 mm in June and 59 mm in July, while for August and September WD exceeded the multiannual means by 20 to 28 mm, respectively. Iar showed also extreme values for this region, i.e. lower than 0.27 mm/mm (except May with 0.95 mm/mm).

Table 1: Climate characteristics as monthly means for year 2012 at Valu lui Traian experimental site, Dobrogea region

Month: **Climatic parameters**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Mean/ Sum**
Temperature (ºC)	13.5	18.6	22.9	26.2	24.5	20.0	16.0	**20.2**
Precipitation (mm)	24.6	110.3	3.6	10.4	22.8	5.9	33.0	**210.6**
ETo (mm/day)	3.09	3.73	5.42	5.37	4.13	2.77	1.51	**3.7**
ETo (mm)	92.8	115.5	162.7	166.6	128.0	83.0	46.9	795.5
WD (mm)	-68.2	-5.2	-159.1	-156.2	-105.2	-77.1	-13.9	**-584.9**
Iar (mm/mm)	0.27	0.95	0.02	0.06	0.18	0.07	1.27	**0.26**

For the year 2012, in the clean cultivation groundcover management system ETc values were higher by about 10 mm in May, 30 mm in June and 25 mm in July, versus the monthly means, whereas IWRs values were higher by 70 mm in June, 60 mm in July, 10 mm in August and 25 mm in September. For the mowed sod system, ETc differences were higher by about 15 mm in May, 40 mm in June and 35 mm in July, and IWRs values were higher by 80 mm in June, 60 mm in July, 20 mm in August and 30 mm in September.

Conclusions

The climatic features characterizing Dobrogea indicate that this area should be included in the semi-arid regions of Europe. Even if it is not in the Mediterranean zone, this region would probably suffer more severely than other regions of the country due to actual and future global changes. There are two important ways for water saving in fruit growing in general, and peach and apricot orchards in particular, in Dobrogea; one is the clean cultivation groundcover management system that allows water to be taken up only by fruit tree roots, no sod or weeds involvement. The other is application of the deficit irrigation method that decreases fruit yield to a small extent versus the fully irrigated orchards and enables water saving to a great extent, i.e. to about half of the fully irrigated method. Irrigation water use efficiency is also higher in this second case.

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Coping with desertification in Iran through improved water use: lessons and constraints

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Abstract

Desertification is one of the most serious environmental and social-economic problems in the world today. Iran as a country located in arid and semiarid zone is facing this problem. Intensive developmental activities, population pressure, urbanization, and resource exploitation in last decades together with scarcity of water and adverse natural conditions have accentuated desertification. Improvement in water conservation is crucial for a sustainable agriculture. It is estimated that due to water constraints only about half of the total cultivable area in the country is actually used for agriculture. Increasing crop production per unit of water with the aim of optimum usage of water resources and food security is a major challenge for all stockholders. The government is emphasizing on developing controlled irrigation methods such as pressurized irrigation, green house cultivation, and use of pipes instead of open canals for carrying water for enhancing water use efficiency. This paper discusses efforts being made for combating desertification and achieving sustainable agriculture in Iran.

Introduction

Desertification is one of the most serious environmental and social-economic problems in the world today. Iran, with an area of 165 million hectares (Mha), is located in a semiarid region of the Middle East. Distribution of precipitation is uneven. The average annual precipitation is 252 mm which is less than one third of the world average. While annual precipitation usually exceeds 2,000 mm in some of the northern parts of the country, it may be less than 20 mm in desert areas. Although water surpluses exist in the mountain regions, the areas of high population density and high water demand are hundreds of miles away. Thus of total water received through rainfall 70% reaches 25% area and the remaining 30% reaches 75% area.

The average renewable water in Iran is 90 billion cubic meters only (52 billion cubic meters groundwater resources and 48 billion cubic meters surface water resources). Given the high population increase and recent persistent drought conditions, Iran's average annual supply of renewable freshwater per person fell from 2,254 m^3 in 1988 to 1,950 m^3 in 1994, and the estimated figure for 2020 is 1,300 m^3. Biswas (1998) believes that generally a country will experience periodic water stress when freshwater supplies fall below 1,700 m^3 per person per year. Iran is thus encountering water stress.

The spatial distribution of water resources in Iran is highly uneven. Almost 30 percent of all annual freshwater of Iran is concentrated in the southwestern part of the country, where only a very small percent of the population is located. The population of Iran in the rest of the area has reached its maximum capacity from water resource availability point of view. Hence policies focused on sustainable demand management are needed (Alizadeh & Keshavarz 2005). Of the total area of 165 million ha in the country, agricultural land is 18.5 Mha of which irrigated lands accounts for 59% in comparison to 16% of the average irrigated lands in the world. With growing population there is increased pressure for rapid water and land development. Urbanization and industrialization have further raised the demand for water, but at the same time have reduced the supply for agriculture.

Iran faces frequent occurrence of drought, particularly in the vast central plateau and east and south of the country. Rapid growth and improper distribution of Iran's population in the desert and semi-desert regions together with the occurrence of drought has exacerbated land degradation. To address this problem, the Government is taking extensive measures, through public participation, to conserve natural resources of land and water and protect residential and industrial infrastructures in 14 provinces, exposed to desertification (NAP 2004). This paper discusses measures to cope with desertification for achieving sustainable agriculture in Iran.

Agricultural development

Since 1994 the UNCCD encourages the international community to confront the existing challenges of desertification for sustainable development and achieving the Millennium Development Goals. Based on the Convention, the member countries had agreed to develop their policies, strategies and priorities in the format of a National Action Programme to fulfill the objectives of the Convention. Iran has made a strong political commitment to the Convention to reverse the desertification trend (NAP 2004).

Agriculture plays a key role in national food security and economic well being of the people. According to the last census conducted in Iran, the sector employed 22 percent of the total economically active population in 2009. Agriculture also provides livelihoods to the population in rural areas, which account for 30 percent of the total population (NIP 2012). It is estimated that about 37 million ha or 21 percent of the total area of the country are cultivable. According to the Ministry of Jihad-Agriculture the total cultivated area for the period 2007-2009 estimated at 18.5 Mha accounts for around a half of the cultivable area. Of these, 6.4 Mha are under irrigated crops, 6.2 Mha under rain fed crops, and about 3 Mha under horticulture crops. There are an additional 8.4 million ha dedicated to permanent pastures (NIP 2012). The limited available water resources in the country have been a constraint for the further development of land for agriculture.

The irrigation potential, based on land and water resources has been estimated at about 15 Mha, of which 8.13 Mha in 2003 were already equipped for irrigation. About 55 percent of that area is irrigated by groundwater and the rest is irrigated with surface water sources and treated wastewater. Surface irrigation is the main technique covering 91.4 % of the irrigated area. Drip and sprinkler irrigation cover 5.2 and 3.4 % respectively. Agriculture is the main water consumer, with 88.6 km^3 (92 percent of total withdrawals) used in 2010 (NIP 2012). The global climate changes would result in an increase in temperature, and frequency of occurrence of floods and droughts. Agriculture will be obviously affected by all these changes, especially in rain fed areas (NIP 2012). Long-term development strategies for water resources of Iran include major issues of demand management, equity in water distribution such as inter-basin transfer, and training. Increasing water productivity is one of the main goals of Iranian irrigation policy.

Having the objective of optimum usage of water resources and food security, some policies have been implemented on the ground. These include advanced irrigation systems, production in green houses, irrigation network development, and use of pipes instead of open canals for carrying irrigation water.

Irrigation efficiency

Irrigation efficiency is a critical measure of irrigation performance. Irrigation efficiency is defined in terms of (a) the irrigation system performance, (b) the uniformity of the water application, and (c) the response of the crop to irrigation. Each of these irrigation efficiency measures is interrelated and will vary with scale and time. Irrigation efficiency affects the economics of irrigation, the amount of water needed to irrigate a specific land area, the spatial uniformity of the crop and its yield, the amount of water that might percolate beneath the crop root zone, the amount of water that can return to surface sources for downstream uses or to groundwater aquifers that might supply other water uses, and the amount of water lost to unrecoverable sources (salt sink, saline aquifer, ocean, or unsaturated vadose zone). The enhanced understanding of irrigation efficiency can improve the beneficial use of limited and declining water resources needed to enhance crop and food production from irrigated lands.

Irrigation application efficiency (E_a) in various irrigation systems is given in Figure 1 (Sohrab and Abbasi 2012). The lowest application efficiency was reported in traditional surface irrigation systems. Among the surface irrigation systems, basins provided higher application efficiency followed by furrows and borders. Among the sprinkler irrigation systems, center pivot and linear systems provided higher E_a and solid systems lower E_a. Overall, E_a in surface and pressurized irrigation systems was 52.3 and 62%, respectively. In general, E_a in Iran varied between 25.2 and 83.6%, and in last two decades mean E_a was 50.4 and 58.6% respectively.

Total irrigation efficiency (E_t) was about 35% in 1999 (Deghanisanij *et al.* 1999), however by investment in improving irrigation methods, on-farm practices, cropping system, land consolidation, seeds and variety improvement etc., irrigation efficiency increased and varied from 41.6 to 45.8% (assuming 75.9% and 83.7% for traditional and modern irrigation networks, respectively). Although, it is lower than the average of the world irrigation efficiency (45% for developing countries and 60% for developed countries), this indicates nearly 1% annual increase since 1999 (Sohrab and Abbasi 2012). A problem with the concept of efficiency, even with basin efficiency, is that it refers only to physical quantities of water. It does not capture differences in the value of water in alternative uses**.**

The International Water Management Institute (IWMI) has reported that the average net irrigation requirement in Iran for cereal and other field crops is 5,100 and 8,100 M^3/ha, respectively. Ministry of Energy, which is in charge of water allocation in Iran, estimated the average amount of irrigation requirement to be 5,200 M^3/ha. The average of values published by different consulting engineers is 5,900 M^3/ha. Considering these figures, the overall irrigation efficiency in Iran would be something between 48 to 55% which is quite different from the figures presented by various sources (Keshavarz *et al.* 2005). This is mainly due to deficit irrigation that farmers practice due to water shortage.

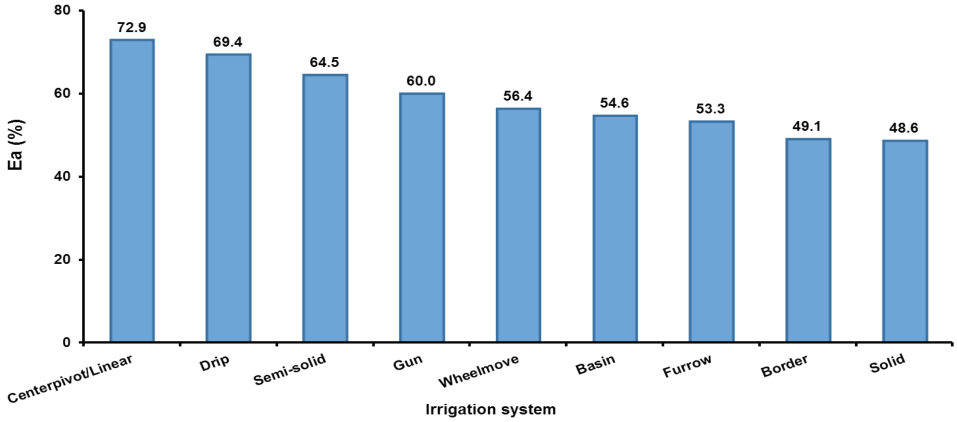

Figure 1: Irrigation application efficiency of different irrigation systems in Iran.

Advanced irrigation systems

The relative use of the different irrigation systems for the period of 1973-2010 is presented in Figure 2. As shown, most of measurements have been carried out on traditional surface irrigation methods and less evaluation made on pressurized irrigation systems (Sohrab and Abbasi, 2012).

Pressurized irrigation system (PIS) developed in Iran during last two decade rapidly because of its advantages compared to traditional systems. Different types of PIS technology transferred to Iran and the level of related internal industry developed significantly during last two decade (Dehghanisanij & Akbari 2011). In this regard, more precise irrigation systems such as sprinkler irrigation, mechanized sprinkler irrigation, drip irrigation and subsurface drip irrigation were introduced, in this order.

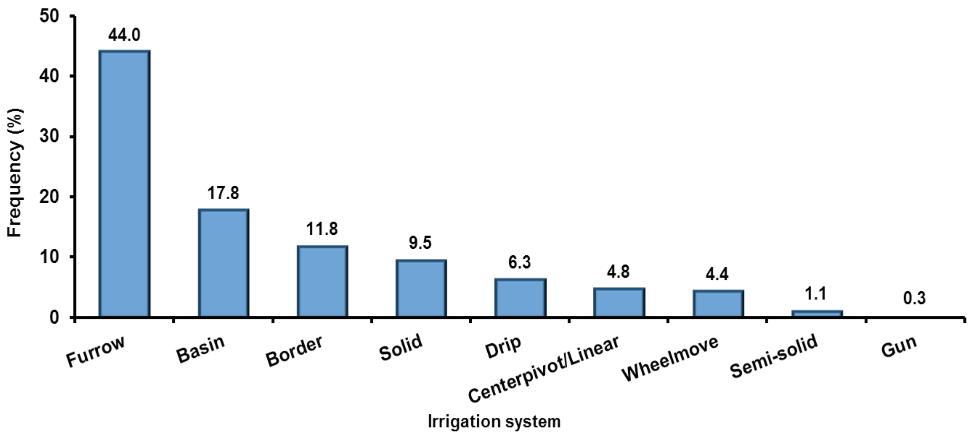

Figure 2: Use of different irrigation systems, 1973-2010.

PIS development in Iran during last two decade is presented in Figure 3. By the end of 2012, total area under PIS exceeded 1,250,000 ha of which 40% is under micro irrigation, mostly drip irrigation (DI) and subsurface drip irrigation (SDI). Agricultural Engineering Research Institute

(AERI) in Iran has been working on SDI for different crops specially using saline water. AERI recommended SDI for pistachio. But because of water quality and lack of enough knowledge amongst the farmers on design and management and operation of SDI, the governmental has not given subsidy to support it for all the crops or fruit trees yet. SDI study for maize, olive, citrus and palm is on-going in AERI.

There is the possibility of developing pressurized irrigation for about 3.5 Mha (almost 50% of the irrigated area) in the country. Hence, the Iranian government is committed to pay interest free loans for pressurized irrigation to persuade the farmers to use such methods. In 2011 governmental subsidy for pressurized irrigation system was 85%. There are still some constrains on the way of developing advance irrigation systems such as: irrigation management, energy prices, cost of the system, farm area development instead of water saving, water quality.

Water productivity improvement

Water use efficiency (WUE) is simply defined as the amount of production per unit of water. A key to mitigate the problem of water scarcity in Iran would be increasing the WUE. High values of WUE in irrigation have not been because of a certain irrigation system but because of increased yields due to better crop management. By proper water management, converting traditional irrigation systems to modern systems, and completion of irrigation networks, the irrigation efficiency is expected to increase up to 50 to 60%. This will allow the expansion of area under irrigation from 2.5 Mha to 3.5-4.3 Mha. Overall, WUE in Iran was estimated to be 0.8 kg/M^3 in 2000 (Heydari *et al.* 2006) and currently is somewhat higher being about 1 kg/m^3 (Abbasi *et al.* 2006). In order to fulfill food requirements, WUE should be increased to about 1.6 kg/M^3 in the next decade. This implies that the institution, structure and procedures of water allocation in agriculture sector should be modified. This would call for emphases on special prioritization, policies, modernization, and productivity management.

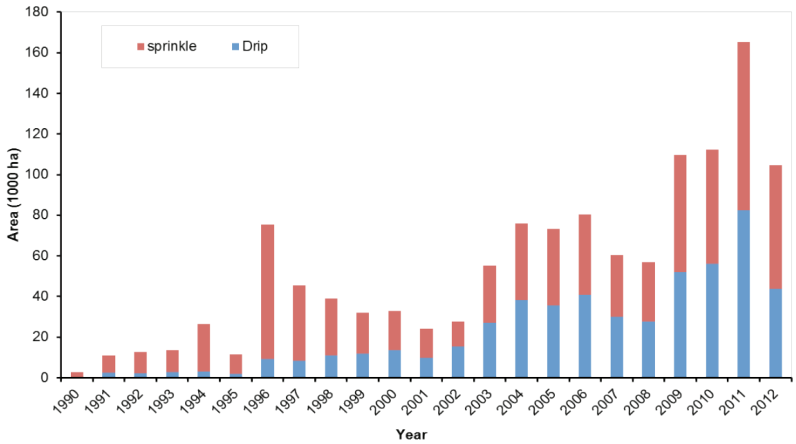

Figure 3: Pressurized irrigation system development in Iran

Based on research of AERI, as shown in Table 1, converting the surface irrigation to drip irrigation can improve water productivity in different crops.

Table 1: Effectiveness of pressurized irrigation systems

Crop	Water productivity (kg/m^3)	
	Surface irrigation	Drip irrigation
Watermelon	3.9	12.2
Melon	3.5	11.9
Maize	0.7	1.9
Potato	0.6	2.3
Cotton	0.2	0.35

Irrigation network development

The water in the surface irrigation schemes arrives through a combination of gravity and water lifting systems. Most of the dams constructed in Iran are for irrigation purposes with main and secondary canals built downstream, covering a total area of 1.98 million ha in 2011 (IWRMCo 2011) and which are called modern systems. The rest of the irrigated areas have traditional canals built by farmers that in many cases have to be rebuilt every year. Small holder schemes (<10 ha) cover 50 percent of the total area for irrigation, medium size schemes (10-50 ha) 40 percent and large schemes (>50 ha) 10 percent. The average holding size of irrigated area is 2.9 ha.

Irrigation schemes in Iran can be classified in to 4 categories as follows:

1. ***Modern irrigation systems***: These systems have secured water supply through a reservoir dam, rivers with sufficient basic discharge and intake structures such as diversion dams, or pumping stations with primary and secondary concrete line canals. According to IWRMCo (2011) data of October 2011 there were 94 modern irrigation and drainage systems covering 1,85 Mha.

2. ***Semi-Modern irrigation systems:*** These systems have either water diversion structures on the rivers with secured basic discharge and equipped with a water conveyance main canal or they are supplied by a series of traditional reveres in tail reach of the reservoir dam. They do not have reservoir dams or secondary concrete lined canals. The country has about 500 of these s covering 598,450 ha of land. The total water conveyance efficiency in these systems was about 83 percent in 2010-2011 (IWRMCo 2011).
3. ***Traditional irrigation systems:*** They are usually within limits of cities, villages, and fields. Water is taken from rivers, water runoffs or pondage through traditional canal intakes.
4. ***The other irrigation ones:*** These include agricultural areas belonging to agro-industries and cooperatives. They include small and large areas independently irrigated by well, Qanats or springs. They generally do not use the dam-regulated water; however, there may be some exceptions.

Regarding efficient use of soil and water resources, development of dams and irrigation networks has been prioritized: 1) water resources management and conveyance and distribution of water to lower part of dams and 2) facilitating water availability for water users. Table 2 shows the area developed by irrigation networks and the potential for development in Iran.

Table 2: The area developed and potential for development of irrigation networks in Iran

Development of irrigation networks	**(Mha)**
Total lands in downstream dams	3.894
Lands with main irrigation networks	1.8
Lands with secondary irrigation networks	0.925
Potentials for main irrigation networks	2.1
Potentials for secondary irrigation networks	2.9

Development of greenhouses

In order to fulfill quantitative and qualitative goals of the fourth development plan and twenty-year outlook of the country in agricultural sector, application of the latest technologies to improve productivity per unit of area is necessary. Production in controlled environment is one approach for efficient use of soil and water resources in Iran. Some of the main advantages of greenhouse productions are: controlling environmental factors and production in the off season, WUE improvement by using advance irrigation methods, efficient use of all agricultural inputs, increase in yield as well as quality, and finally creation of jobs. Moreover, geographical location and climate of our country, with long hours of full sun light and different climatic conditions, and close proximity to regional market provide suitable conditions for development of greenhouse agriculture in Iran. The total area under greenhouses in the country up to 2006 was not more than 6500 ha. By the end of 2011, it has increased to reach more than 7800 ha. Potential development of greenhouses in Iran from 2010 to 2014 shown in Figure 4. By the end of 2014 the area under greenhouses will be more than 9400 ha.

Studies on field and greenhouse grown cucumbers in Iran showed that yeild in greenhouse was 250 ton/ha as against about 20 ton/ha in the field. The water use in greenhouse was 7500 m^3/ha while it reached 18000 m^3/ha in the field (Dehghanisanij *et al.* 2007). There are however some constrains in the development of greenhouses in Iran. These include knowledge on management, cost of energy, marketing and import/export policy, and water quality.

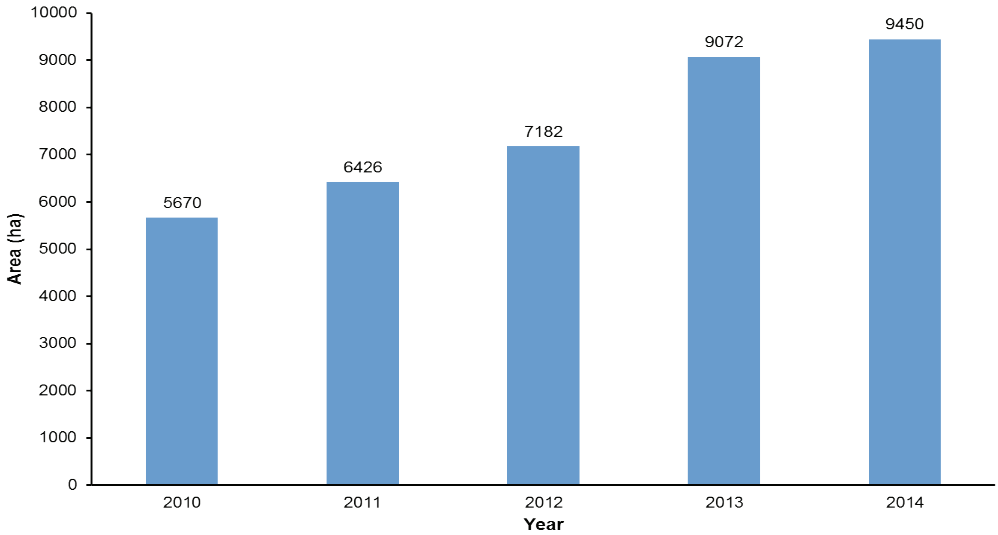

Figure 4: Potential development of greenhouse agricultures in Iran.

Conclusion

Rapid growth and uneven distribution of population in the desert and semi-desert regions of Iran together with the occurrence of drought has exacerbated land degradation. Improved water resources can provide a solution**.** Long-term development strategies for water resources of Iran include major issues of demand management, equity in water distribution such as inter-basin transfer, public training, and recycling of waste water. Increasing water productivity is one of the main goals of Iranian irrigation policy. Accordingly, some policies have been implemented including introduction of advanced irrigation systems, increasing the water productivity by developing the greenhouse agriculture, development of improved irrigation network and the use of pipes instead of open canals far carrying irrigation water.

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The role of on-farm management on sustainable irrigated agriculture in arid and semi-arid region - A case study in Karkheh River Basin – Iran

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Abstract

The Karkheh River basin (KRB) is an important agricultural zone, located in southwest Iran. In the lower KRB, some irrigation water is lost during conveyance and field application, resulting in low irrigation efficiency and the risk of land and water resource degradation. Water productivity (WP) for wheat and barley is less than 0.5 kg/m^3 and for maize is about 0.4 kg/m^3 – lower than the country averages of 0.8 kg/m^3. A study was conducted in lower KRB, in Sorkheh district of Evan Plain, in 2005 to 2007, to identify causes of low WP and to introduce measures for its improvement. The study area has a semi-arid climate with average rainfall of about 350 mm. Seven irrigation units, each consisting of several farms with similar sources of irrigation water, were identified as follows: two units using only wells, three units receiving water from irrigation network canals where water delivery is on a variable rotational basis and depends on the operation of the pumping station feeding the network from the river, one unit pumping water directly from the river, and one unit using both network and well water. In each unit, three farms were selected with regard to variables such as distance to water source, method of water supply, crop cultivar, management of irrigation, and farming practices. WP of each farm was determined. Farms irrigated by water from the network consumed more water but had lower grain yields. Wheat yield and water use efficiency were higher in fields following corn than fallow. The inflow of the most efficient unit was 3.5-4 l/s/m. The most sensitive stage to drought stress was from heading until grain ripening; therefore, three or four irrigations (each 50 mm) are recommended during early spring. Assuming a fixed yield resulting from the application of proper irrigation practices and/or utilization of irrigation systems with higher application efficiency, the irrigation water efficiency can be enhanced by about 30%.

Introduction

Wheat is the main crop in Iran. In 2004/05, the total irrigated area under wheat was 2.2 Mha, with an average yield of 3 t/ha, while the dryland wheat area 3.51 Mha with an average yield of 0.7 t/ha. The wheat self-sufficiency ranged between 60% and 80%. To achieve complete self-sufficiency, an average wheat yield of 4.8 t/ha is required from the irrigated and 1.16 t/ha from the rainfed cultivation. The main factors for low yields are untimely and inadequate application of agricultural inputs (seed, fertilizer, herbicide, etc.) and high levels of waste at various stages of production, limited water resources or lack of appropriate irrigation, losses from pests, weeds, and blight because of inadequate control, lack of or inappropriate use of agricultural equipment and machinery, inadequate investment in agricultural research, training, and extension, lack of appropriate planning and policies for agricultural production.

Shpiler and Blum (1991) report that the most sensitive periods for moisture stress in wheat are the double-enation and pollination stages because of the negative effect of the stress on the spikelets and number of seeds. Royo *et al.* (2000) indicated that moisture stress from pollination to ripeness, especially with increased temperature, may lead to pre-mature senescence of leaves and reduction in the time and rate of kernel formation and the average seed weight. Water shortage during pollination will decrease crop performance due to a reduction in spikelet number and fertility. Fischer et al. (1981) found that the most sensitive stage to water stress is 15 days before pollination, which broadly influences the number of spikes. This period (between 5 and 16 days before spike formation) coincides with the elongation of the stems, anthers, and pistils.

Farhad Nato (2005) indicated that timely and proper irrigation can improve wheat yield by 15%, while late delaying irrigation during blooming may decrease it by 8%. An additional irrigation during physiological ripening results in 15% more production. Accordingly, with adequate irrigations from the flowering stage to physiological ripening, yield stability will increase. If the last irrigation is applied 3 days after flowering (appearance of the flag leaf) in southern Khuzestan and similar areas, the root will exploit the deep soil moisture and this will improve the remobilization process.

Agronomic practices that reduce soil water evaporation via a larger plant canopy and early ground cover and, at the same time increase the crop's ability to extract soil water, may increase the amount of water transpired and, consequently, the WUE (Cooper *et al.* 1983; French and Schultz 1984; Siddique *et al.* 1990; Zhang *et al.* 1999). Nitrogen deficiency is a major constraint in canopy development in the Mediterranean region (Anderson 1985). Crop responses to N fertilization depend on the level of water available (Pala *et al.* 1996). Application of fertilizer not only increases plant shoot and root growth (Brown *et al.* 1987), but also increases ET through a larger root system and greater extraction of stored water (Cooper et al. 1987a). In addition, a large and early canopy cover resulting from the application of N can reduce soil water evaporation and increase crop WUE (Zhang *et al.* 1999).

Crop-water production functions for wheat were derived from SI experiments conducted in Syria (Zhang and Oweis 1999), the North China Plain (Zhang et al. 1999) and Oregon State, USA (English and Nakamura 1989).

In WANA, water resources are generally scarce, and agriculture's share of these resources is declining because of competition from the domestic and industrial sectors. The amount of rainfall is low and generally poorly distributed, so periods of soil water deficiency occur during the grain-filling stage of wheat almost every year (Oweis *et al.* 1992). As a result, crop yield and WUE are generally low and variable. The production of 1 kg of wheat (*T. aestivum* L.) grain under fully irrigated conditions requires from 1 to 2 m^3 of irrigation water (Perrier and Salkini 1991); in rainfed areas it requires from 1 to 3 m^3 of rainwater (Cooper *et al.* 1987a; Perrier and Salkini 1991). Since water is the major limiting factor for agriculture in the WANA region, improving WUE is vital to meet the increasing food demand (Cooper *et al.* 1987b). Application of a limited amount of water to rainfed crops when precipitation fails to provide the essential moisture for normal plant growth, the supplemental irrigation, has shown the potential to alleviate the adverse effects of unfavorable rain pattern and thus improve and stabilize crop yields (Perrier and Salkini 1991; Oweis *et al.* 1998; Zhang and Oweis 1999). No comprehensive information is available on efficiency of water consumption in Iran, particularly for different basins. Only some case studies have been conducted in different regions of the country.

Based on the results of two national studies on irrigation efficiency conducted by Heidari and Haghayeghi Moghaddam (2001) at different locations of Iran, wheat water use efficiency (yield/applied water) ranged from 0.34 to 0.84 kg/m^3. The findings imply that the irrigation method and its management can significantly affect water consumption. Heidari *et al.* (2006) analyzed the WUE of agricultural plants in different regions (Kerman, Hamedan, Moghan, Golestan, and Khozestan) for various crop management scenarios. The WUE values were 0.75 kg/m^3 for wheat, 0.64 kg/m^3 for sugar beet (sugar yield),2.06 kg/m^3 for potato, 5.58 kg/m^3 for field corn, 1.46 kg/m^3 for alfalfa (dry weight), 0.56 kg/m^3 for oat, and 0.29 kg/m^3 for sugar cane (sugar yield). Management was the most important factor influencing water efficiency. Therefore, information dissemination and extension were powerful levers for improving of WUE.

The farmers in northern lands of the KRB, where this study was conducted, have lower awareness of irrigation management in comparison to other regions. Efficient use of land and water resources in this area will have a significant effect on the agricultural economy of the region, and the nation as a whole. This study deals with the WUE of wheat in the Sorkheh irrigation grid and addresses the factors that influence it.

Table 1: Chemical and physical properties of the soil of the selected farms in 2006

Field no	Soil texture	Element		pH	EC (dS/m)	Organic carbon (%)
		K (ppm)	P (ppm)			
1	L	149	7.5	7.5	2.9	0.4
2	Si.L	1589	6.9	7.6	2.3	0.61
3	Si.L-L	149	5.2	7.4	2.55	0.38
4	L	149.2	2.6	7.8	1.9	0.41
5	L	94.8	2.6	7.8	1.9	0.34
7	L	121	4.7	7.47	2.4	0.42
8	L	69	16.2	6.9	2.5	0.34
9	Si.L	158.6	7	7.2	6	0.61
10	L	121.4	9.7	7.6	2.3	0.48
11	L	95	8.4	7.6	1.2	0.39
12	Si.L	94.8	1.9	7.7	1.4	0.25
13	L	130.6	4.2	7	1.7	0.46
14	Si.C.L	319.6	21	7.3	4.4	0.54
15	Si.L	262.6	7.4	7.5	4.1	0.49
17	Si.L-Sa.L	121.4	3.5	7.5	4	0.27
18	Si.L	60	1.1	7.0	3.3	0.07
21	Sa.L-L	131	9.4	7.6	1.25	0.39
22	Sa.L	60	4.3	7.6	1.5	0.29
23	L	86	5.2	7.3	2.2	0.37

.L – loam; Si.L – silty loam; Sa.L – sandy loam; Si.C.L – silty clay loam

Materials and methods

This study was carried out on wheat during the period 2005 to 2007 in Sorkheh. Based on the sources of farm water supply, the following seven irrigation units were selected; two units using wells, three units receiving water from irrigation network canals, one unit that pumps water from the river, and one unit that uses both the canal network and wells. In each irrigation unit, three farms were chosen. The choice was based on the distance from the farm to the water source, the crop cultivar, management of irrigation, and farming practices. The total amount of applied irrigation water (I, m^3/ha) was measured (inflow) using a calibrated cutthroat flume installed at the farm water entrance. The runoff (outflow) was measured using a calibrated cutthroat flume of smaller size installed at the end of the farm.

The total yield of wheat was measured based on the total yield harvested by combine. Simultaneously, three samples, each of 6 m^2 (two 4-m ridges) were cut from each farm to measure the number of plant per unit area, kernel yield, and total dry matter.

The physical and chemical properties of the soil were analyzed based on soil sampling before the crop season. Soil samples were collected at 0 cm to 30 cm depth from five different locations on the farm and mixed for analysis.

To calculate the daily evapotranspiration, daily climatic data, such as the minimum, maximum, and average temperature, solar radiation, humidity, wind speed, hours of sunshine, evaporation from a Class A evaporation pan, and daily rainfall were collected from Dezful weather station.

To monitor the farm situation and management, following data were collected during the irrigation season:

- ***Farm specification***: Length of furrow, slope of the land in the direction of irrigation, area of farm under irrigation.
- ***Crop and farm management***: Crop variety, farming, and breeding activities, date of tillage operations during the crop growth stages, rate and timing of fertilizer and pesticide applications, seeding rate
- ***Crop calendar***: Time of planting, duration of the initial stage of growth (germination), beginning of generative stage, duration of generative stage, beginning of ripening stage, duration of ripening stage, harvest date.

Wheat WP ($WP_{(I+R)}$) was calculated using equation 1:

$$WP_{I+R} = \frac{Y}{I+R} \qquad (1)$$

where R m^3/ha is the amount of rainfall. The irrigation application efficiency (IE) (expressed as a percent) for all the irrigation events was calculated using equation 2:

$$\mathbf{E} = \frac{ETci}{I} \times 100 \qquad (2)$$

where ETci (m^3/ha) is the crop water requirement from the first irrigation after the winter season. Wheat WP_{ETc}, based on the wheat water requirement (ETc m^3/ha), can be calculated as follows:

$$WP_{ETc} = \frac{Y}{ETc} \qquad (3)$$

Results and discussion

Soil analyses results are presented in Table 1.

Climatic characteristics of the region

The average daily temperature and monthly climatic and meteorological data of Safiabad-Dezfoul region for year 2005/6 are provided in Tables 2.

Table 2: Climatic characteristics in Sorkheh during 2005/06

Month	(Temperature (ºC			Rain ((mm	Max wind speed		(%)RH	Sun shine ((hr	Pan evapora- (tion (mm
	Max	Min	Ave		(m/s)	date			
Dec	15.2	5.4	10.3	90.7	13.0	16	77.4	159.7	34.9
Jan	16.4	5.3	10.8	60.5	11.0	11	75.5	168.4	41.2
Feb	20.4	9.0	14.7	52.7	11.0	3	71.8	184.3	69.7
Mar	23.7	9.9	16.8	66.3	17.0	26	65.2	207.7	111.4
Apr	29.2	16.2	22.7	60.1	17.0	13	59.9	171.9	153.7
May	40.6	22.5	31.5	5.0	12.0	15	40.9	205.9	265.5
Jun	45.3	23.9	34.6	0.0	11.0	10	35.4	336.7	371.6

Wheat water productivity

The data are shown in Tables 3 and 4. In the first year, the average grain yield was 4430 kg/ha with four irrigations and an average water use of 4840 m^3/ha. Therefore, the average irrigation and rain WP ($WP_{(I+R)}$) was 0.97 kg/m^3 in the first year. However, during the second year the average grain yield was 5609 kg with an average water use of 15,770 m^3/ha, resulting in an average $WP_{(I+R)}$ of 0.40 kg/m^3. There was approximately a 10% reduction in crop yield as a result of an attack by aphids during 2005/06.

Figure 1 shows the total amount of water applied versus the yield for the seasons 2005/06 and 2006/07. The $WP_{(I+R)}$ has a positive relation with the yield, while there is a negative relation between $WP_{(I+R)}$ and the amount of water used. The slope of the regression line is the same for grain yields in both the years of the experiment. The slope of the changes in $WP_{(I+R)}$ with the amount of water used is to some extent steeper in the second year than in the first.

The mean grain yield, applied water, and $WP_{(I+R)}$ for the various fields with different sources of water, the different cultivar planted, and the different land use history before planting were studied. Accordingly, farms irrigated by water from the network consumed more water in both years. The average grain yield in the 2005/06 season was highest where water was applied from the well, and the network and well combination. In 2006/07, grain yield was highest for water applied from the network and well combination only. Obviously, higher water consumption on the farms drawing from the irrigation network resulted from having a reliable water allocation from this source – water was available when it was needed.

Among the wheat cultivars, the grain yields of 'Chamran' and 'Vierinak' were quite similar. The grain yield from the cultivar 'Dez' was relatively constant over the two seasons. On the farms

Table 3: Agronomic practices and wheat WP in 2005/06

Field no.	Variety	Seed rate (kg/ha)	Germination date (dd. mm.yyyy)	No. of irri	Border length (m)	Average irri depth (mm)	Average discharge rate (l/s)	Crop water requirement ETc-req (mm)	Grain yield (kg/ ha)	IE (%)	WP (ETc) (kg/m^3)	$WP_{(I+R)}$ (kg/m^3)
1	Chamran	250	09.12.2005	3	255	79	2.1	125	5,089	0.525	1.605	1.183
2	Vierinak	300	12. 01.2006	3	212	87	2.55	203	4,807	0.775	1.393	1.190
3	Vierinak	300	12. 01.2006	4	262	89	1.96	203	4,674	0.572	1.355	0.940
4	Dez	280	17. 12.2005	3	470	121	2.72	104	5,769	0.287	1.949	1.039
5	Dez	280	12.12.2005	3	362	198		97	3,514	0.164	1.220	0.448
6	Dez	280	12.12.2005	3	472	59		97	4,189	0.551	1.454	1.141
7	Chamran	300	30.01.2006	4	480	73	4.08	242	4,846	0.829	1.434	1.249
8	Vierinak	350	16.12.2005	4	360	74	5.25	113	5,493	0.382	1.807	1.128
9	Chamran	250	18.12.2005	4	275	90	4.41	143	4,003	0.398	1.321	0.771
10	Dez	300	11.12.2005	5	200	93	3.72	117	4,208	0.252	1.362	0.642
11	Dez	154	05.12.2005	4	410	70	2.98	106	4,611	0.377	1.441	0.931
12	Dez	185	05.12.2005	4	300	48	2.05	102	3,652	0.531	1.159	0.902
13	Vierinak	250	18.01.2006	4	383	65	2.87	244	5,736	0.938	1.625	1.554
14	Chamran	270	16.12.2005	3	315	56	3.81	115	4,720	0.680	1.543	1.311
15	Chamran	270	15.12.2005	3	270	96	3.73	109	4,447	0.380	1.482	0.930
16	Chamran	180	20.12.2005	3	235	111	2.69	243	4,865	0.730	1.378	1.098
17	Chamran	280	09.12.2005	8	230	77	5.33	102	3,385	0.166	1.095	0.411
18	Vierinak	250	12.012006	7	235	42	2.42	214	4,509	0.728	1.266	1.034
19	Vierinak	250	12.01.2006	7	240	34	2.24	214	2914	0.895	0.819	0.765
20	Vierinak	280	16.01.2006	4	242	98	4.82	232	3869	0.590	1.135	0.771
21	Vierinak	280	16.01.2006	4	358	87	5.93	232	3241	0.667	0.950	0.709
22	D-79-18	300	16.01.2006	3	375	99	6.81	232	4953	0.781	1.452	1.220

Table 4: Agronomic practices and wheat WP in 2006/07

Field no.	Variety	Seed rate	Germination date (dd.mm.yyyy)	No. of irri	Border length	Average of irri depth (mm)	Average discharge rate (l/s)	Crop water requirement, ETc-req (mm)	Grain yield (kg/ha)	IE (%)	WP (ETc) (kg/m^3)	$WP_{(I+R)}$ (kg/m^3)
1	Sheva	290	13.12.2006	5	208	80	1.60	367	4,734	0.915	1.449	1.027
2	Sheva	330	12.12.2006	5	270	48	1.65	382	4,690	1.579	2.023	1.595
3	Sheva	330	12.12.2006	5	235	68	1.84	382	4,690	1.130	1.909	1.202
4	Dez	300	28.12.2006	12	290	101	3.36	335	2,269	0.276	2.015	0.174
5	Sheva	280	06.12.2006	10	365	111	4.33	347	3,896	0.314	2.164	0.338
6	D-79-18	300	14.12.2006	10	480	87	7.85	350	1,549	0.401	1.285	0.168
7	Vierinak	300	13.12.2006	5	275	165	6.19	348	2,505	0.423	2.254	0.287
8	D-79-18	280	13.12.2006	7	150	212	6.84	356	3,072	0.239	1.528	0.200
9	D-79-18	290	13.12.2006	6	220	107	5.28	356	3,840	0.553	1.929	0.552
10	Star	140	24.11.2006	6	238	114	4.42	332	4,606	0.486	0.752	0.593
11	Star	160	14.12.2006	5	243	129	5.07	331	2,899	0.512	1.455	0.415
12	Vierinak	185	26.12.2006	5	239	155	5.39	347	5,144	0.447	1.453	0.622
13	Vierinak	220	14.12.2006	5	311	64	2.20	335	5,678	1.040	1.971	1.522
14	Vierinak	220	15.12.2006	5	270	138	3.78	335	4,470	0.486	2.211	0.603
15	Vierinak	220	15.12.2006	5	335	123	4.38	335	3,366	0.543	2.123	0.504
16	Chamran	240	06.12.2006	6	253	86	3.62	309	3,818	0.600	1.553	0.634
17	Vierinak	250	24.01,2007	6	229	104	3.86	348	2,238	0.558	1.463	0.345
18	Vierinak	250	24.01.2007	6	181	103	3.59	348	4,006	0.566	1.946	0.627
19	Vierinak	250	26.12.2006	5	357	147	5.27	325	2,384	0.442	1.580	0.304
20	Dez	270	31.12.2006	5	275	122	4.94	334	3,747	0.548	1.929	0.569
21	Dez	280	03.01.2007	5	380	104	3.85	335	6,134	0.645	1.622	1.080

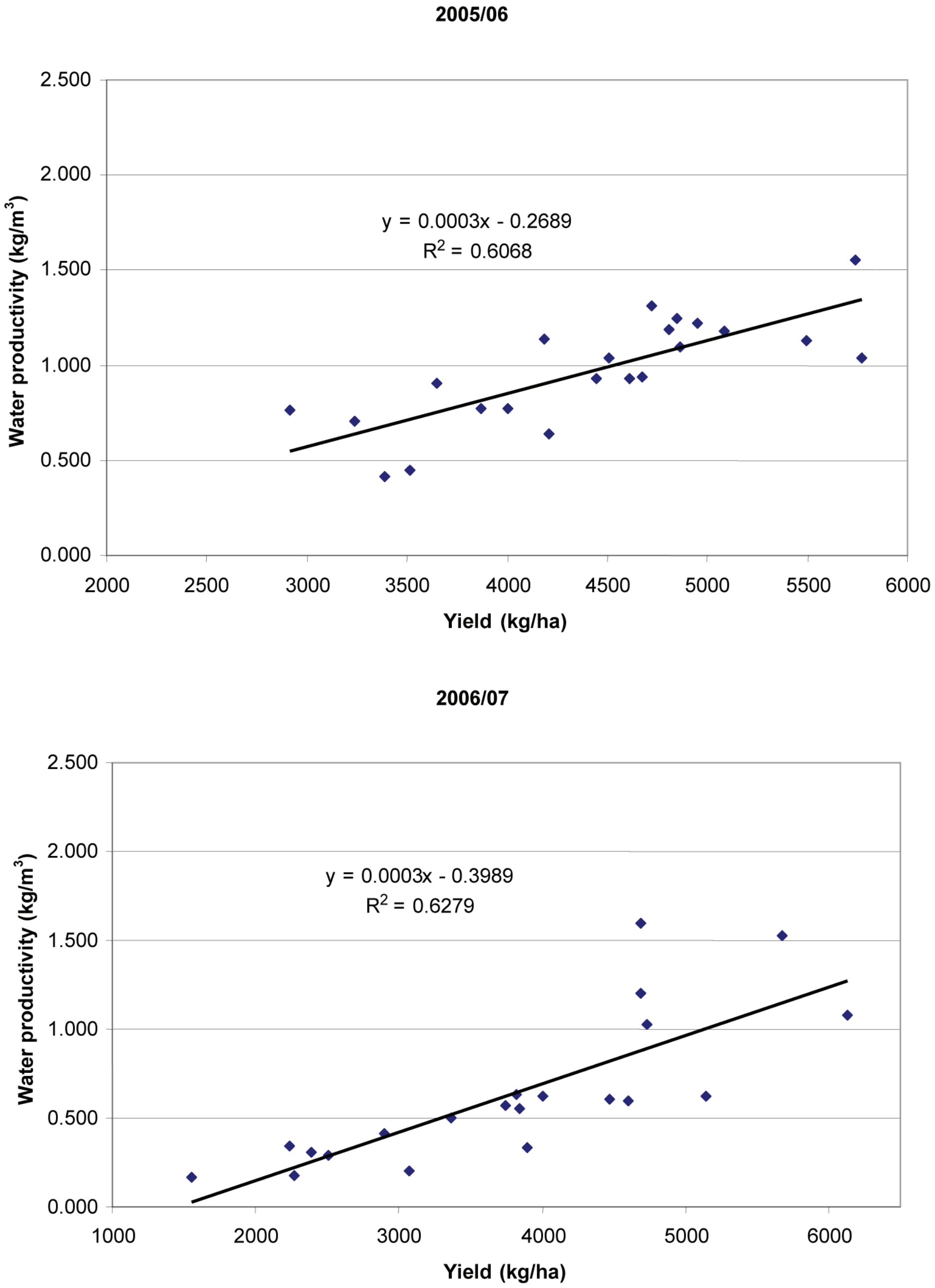

Figure 1: Changes in $WP_{(I+R)}$ with yield on selected farms between 2005 and 2007.

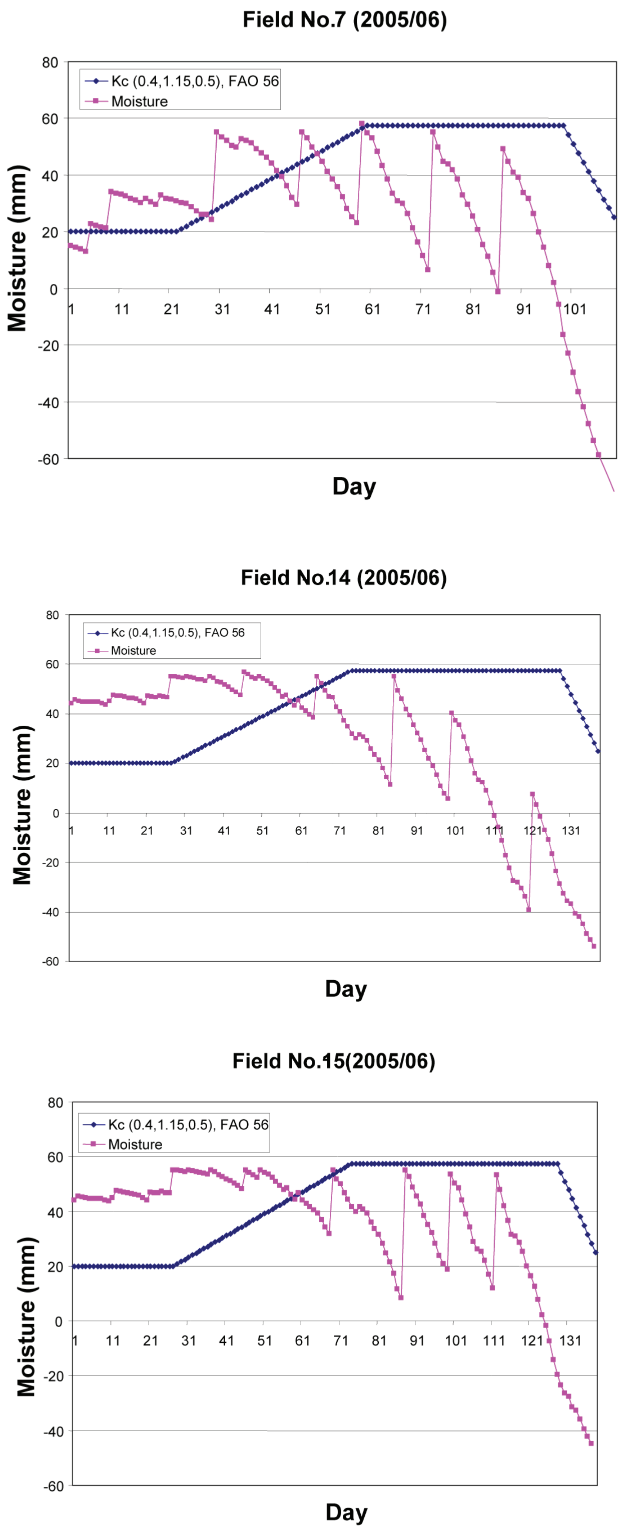

Figure 2: Available moisture balance in the root zone n the Farms 7, 14 and 15.

where wheat was sown after corn, the yield and $WP_{(I+R)}$ were higher than on farms that had fallow before the wheat crop. This was mainly due to the difference in the wheat variety.

Figure 1: Changes in $WP_{(I+R)}$ with yield on selected farms between 2005 and 2007**.**

The interval between irrigations is another management factor that is important and is assessed by determining the available soil moisture balance for the plants during the growth period. The available moisture balance in the root zone during the growing periods on farms 7, 14, and 15 are shown in Figure 2. All three fields are similar in cultivar used and crop rotations. The length of the strip and the inflow rate to the width of the strip are based on recommendations. A negative value for the moisture balance of the soil indicates a lack of water that plants need which led to moisture stress. Farms 14 and 15 are similar in their planting date and irrigation period, but they have different yields. Comparing their soil moisture balances showed that in the case of a drought stress in stages three and four, soil moisture at Farm 15 was kept at field capacity for more days than at Farm 14. It can be concluded that excess soil moisture can lead to a reduction in oxygen in the rhizosphere during the heading stage until grain ripening, and this reduced the grain yield by 10% at Farm 15. Despite the delayed planting date (50 days) at Farm 7 from that at Farms 14 and 15, the reduction in yield due to the delay was compensated for by 60 mm irrigation. Therefore, the on-time irrigation (50-60 mm depth irrigation) after the heading stage until grain ripening is more important than the planting date.

Figure 2: Available moisture balance in the root zone n the Farms 7, 14 and 15.

Summary

- The fertility of the selected farms was low.
- The average irrigation WP for wheat in the Sorkheh site was 0.84 kg/m^3 which can be improved to 1.1 kg/m^3 by improving farm and irrigation management.
- The mean yield was about 4120 kg/ha from 4963 m^3 of applied water.
- Farms with network water resources consumed more water, while the grain yields were higher on farms using wells/network water resources.
- The yields of all three of the varieties mentioned were reduced in 2006/07. The reduction in the yield of the Dez cultivar, however, was less than that of the other two.
- The yield and WP were higher on the farms where the wheat was cultivated after corn as compared to where it was grown after fallow.
- The plant is most sensitive to drought stress from the heading stage until the grain has ripened. Therefore, three or four irrigations (50 mm each) are recommended during the period 15 March to 20 April.
- The recommended length of the furrow is 250m with an inflow rate of 3.5-4.0 L/s.

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Theme 5
Desertification process and control;
Sustainable land use and management in dry areas

Land degradation potential by soil erosion under different land uses in the dry area of Tarim Basin

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Abstract

Tarim Basin generates large quantities of dust that is carried by winds over large areas of Asia and across the Pacific to North America. The northwestern dry area of Tarim Bain is located in the transmission route of dust. The objective of this study was to characterize the potential wind erosion and fine particle emission in the region as affected by five different land uses. Soil from the upper 5 cm layer of the profile was collected from five major land uses in the Basin. Analysis indicated that different land uses had heterogeneous soil texture. Except for Dry channel, all soils were rich in sand, ranging from 60.1 -94.5%. The clay content ranged from zero to 13.28%. There was no significant difference in soil texture between Jujube orchard and cotton, indicating that the crops had no significant effect on soil texture. For D95, the Desert riparian had highest value, the transition zone followed, the cotton and the orchard also had high values, indicating that the soil particle was coarser. The Dry channel had lowest value, was significant finer than others. The particles greater than 0.84mm were not found in any soils, thus there was no non-erodible soil in the study area. The saltation material from five treatments had high percentage except for Dry channel. The five treatments had high suspension content , especially the Dry channel (97.93%), which had highest content of PM 10 and PM 2.5, followed by the Desert riparian. The dry channel and desert riparian had high suspension, PM10 and PM 2.5, the two types of land use must have great concern for dust generation.

Introduction

In arid and semi-arid region, wind erosion is one of the major reasons for land desertification. Aeolian erosion and dust production are major environmental concerns, since atmospheric particulate matter impacts the regulation of surface temperature (Overpeck *et al.* 1996), air quality (Husar *et al.* 2001), and human health (Schwartz 1994). Moving dust is a frequent product of wind erosion (Gillette 1977; Stetler and Saxton 1995) and is often the most visible evidence of erosion downwind from actively eroding fields. Sand-dust events are catastrophic weather phenomena that frequently occur in arid and semiarid areas with enormous effects on eco-environments and human health (Qian *et al.* 2004; Shi and Zhao 2003).

The largest source areas for wind erosion and dust generation are the great deserts of Asia and Africa (Gao *et al.* 1992; Glaccum and Prospero 1980; Prospero 1999; Shaw 1980). Areas within source regions that provide ideal conditions for dust generation include dry lake beds (Reheis 1997; Blank *et al.* 1999), open deserts (Pewe 1986), fallow farm fields and other disturbed lands (Zobeck and Fryrear 1986), and unpaved roadways and building sites (Chow and Watson 1997).

The meteorological statistics of some important source regions for sand-dust events in China showed that the frequencies of sand-dust events were not always significantly correlated with the synoptic and climatic parameters (Hu *et al.* 2001; Liu *et al.* 2003; Qian *et al.* 2004). This has encouraged scientists to consider the influence of other factors while studying the meteorological causes of sand-dust events (Qian *et al.* 2007). The size distribution and stability of soil aggregates have a major influence on the wind erodibility of soils (Tatarko 2001). Characterization of near-surface soil aggregate structural properties such as aggregate-size distribution, stability, and aggregate wettability is crucial to predict soil erosion potential, structural development, soil-water-air-heat fluxes, and SOC dynamics. In fact, knowledge of the resistance of near-surface soil aggregates to the erosive forces of wind and rain is critical in determining the extent to which a soil will erode (Blanco-Canqui *et al.* 2009). PSD data are widely available for soils around the world, it would be advantageous to estimate factors influencing wind erodibility from those data (Chandler *et al.* 2004).

The physical characteristics and chemical constituents of moving dust are heavily influenced by the specific source areas and land use (Chow *et al.* 2003).Wang *et al.* (2006) reported that dust emissions are low from other Gobi desert regions, such as the northern Gurbantunggut and eastern Taklimakan, where high vegetation cover restrained dust emissions or where dust-size particles are not abundant after a long period of strong wind erosion. The model results of Tegen *et al.* (2004) suggest that the contribution to global dust loads from agricultural lands is relatively small, less than 10% of the total. Moulin and Chiapello (2006), on the other hand, provide data that suggest that the small contribution from human-impacted landscapes, as claimed by Tegen *et al.* (2004), may be incorrect, at least in the Sahel (Lee *et al.* 2009). Lin *et al.* (1999) suggested that the ground-surface characteristics of the regions prone to sand-dust events were related to vegetation cover, soil texture and the proportion occupied by bare land.

Tarim Basin generates large quantities of dust that is carried by winds over large areas of Asia and across the Pacific to North America. Akesu area, located in northwestern Tarin Basin, has very serious wind erosion. In recent years, the cultivated land had greatly increased, the total area expanded to 37. 98×10^3 hm^2 during 1991-2005 (Zhou *et al.* 2010). In the last several years, the area cultivated from virgin land had increased at a fast rate; especially for cotton and jujube production, which give high economic benefits. Such lands on the edge of Gobi became more and more common because increasing scarcity of suitable land. In addition, there was area of more than 1000 km^2 in desert riparian along the river, and had some dry channel and a large transition zone. These land uses usual were generally neglected in wind erosion research in Tarim Basin and even in others area.

There are a lot of researches on wind erosion in China. However, investigations on fine particle emission potential and wind erosion under new cultivated land (cotton and jujube) on edge of Gobi, transition zones, desert riparian and dry channel in Traim basin are limited. The objective of this study is to investigate and characterize the fine particle emission potential and wind erosion of soils in five different land uses in Tarim Basin by particle size distribution.

Materials and method

Study site: The study was done in the Akesu area in Xinjiang, in northwestern Tarim Basin, in the upper reaches of Tarim river, with warm temperate arid desert climate (annual precipitation

45 to 61 mm, annual potential evaporation 1,980–2,062mm). With the arid desert climate, desert shrubs and semi-shrubs are dominant.

Sampling and analysis of soil: Soil samples were collected from the upper 5cm layer of the soil profile under five land uses (Fig. 1): 1) Cotton field (Virgin cultivated land), 2) Jujube orchard (Virgin cultivated land, 3) Oasis-desert transition zones, 4) Desert riparian, and 5) Dry channel (41°28'2.496" N, 81°57'40.212" E). There were three replicates for each treatment. The detail was shown in Table 1. The photos of treatments were shown in Figure 2. The soil samples were air-dried and hand sieved through a 2-mm sieve to remove large aggregates, stone, and plant residue. Large aggregates were mechanically fractured to facilitate passage through the 2 mm sieve. Soil passing through 2-mm sieve was used for soil particle size analysis. Particle size distributions were measured using a Malvern Mastersizer S laser diffractometer (Malvern Instrument, Malvern, England) that measures volume percent of particles in 100 size classes from 0.02 to 2000 µm.

Table 1: Details of five land use treatments

No	Treatments	Details
1	Cotton field	Cotton field developed by cultivating virgin land in 2009, drip irrigation.
2	Jujube orchard	Cotton field, developed by cultivating virgin land in 2009, flood irrigation.
3	Oasis-desert transition zones	Oasis-desert transition zones, was close to Taklimakan desert. There was some plant cover (*Alhagi sparsifolia*). The coverage reached about 70 %.
4	Desert riparian	Desert riparian, located in Hotan river riparian. There were some adult *Tamarix chinensis*, *Populus euphratica* and a little reed in this region.
5	Dry channel	The seasonal river, located in Xinhe county. Only had flow of flood water.

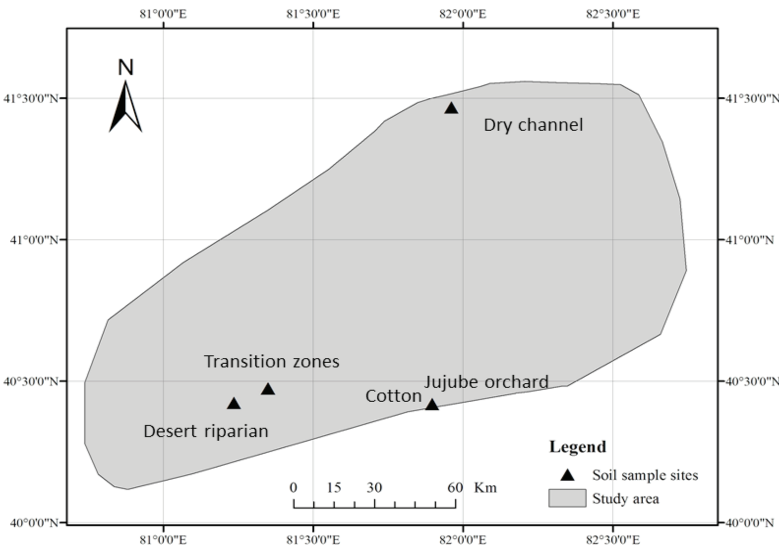

Figure 1: Soil sampling sites within the study area.

Figure 2: The sampling sites from five treatments.

Results and discussion

The five soils tested in this study represent some major soil series in the region (Fig 3, Fig 4). The texture of five soils was different (Table 2). The texture of soil was loamy sand in Cotton field and Jujube orchard, was sandy in the Oasis-desert transition zones, was sandy loam in the Desert riparian, and was silt in the dry channel. Dispersed sample analysis indicated that the Transition zones had highest percentage of sand, and the Dry channel had the lowest. It may be because of the closeness of the Transition zones to the desert. On the contrary, the Dry channel had large amount of sediment deposition from water flow. Except for Dry channel, all soils had high percentage of sand (60.09 -94.50%). The clay content ranged from zero to 13.28%, indicating

Table 2: Soil particle size[1] distribution and texture of soils

Soils	Sand %	Silt %	Clay %	Texture
Cotton	88.79	11.21	0.00	Loam sand
Jujube orchard	85.01	14.41	0.58	Loam sand
Transition zones	94.50	5.50	0.00	sand
Desert riparian	60.09	37.89	2.03	Sandy loam
Dry channel	5.80	80.92	13.28	Silt

[1]Sand, 0.05-2 mm; Very fine sand, 0.05-0.1 mm; Silt, 0.002-0.05; Clay, 0.002mm

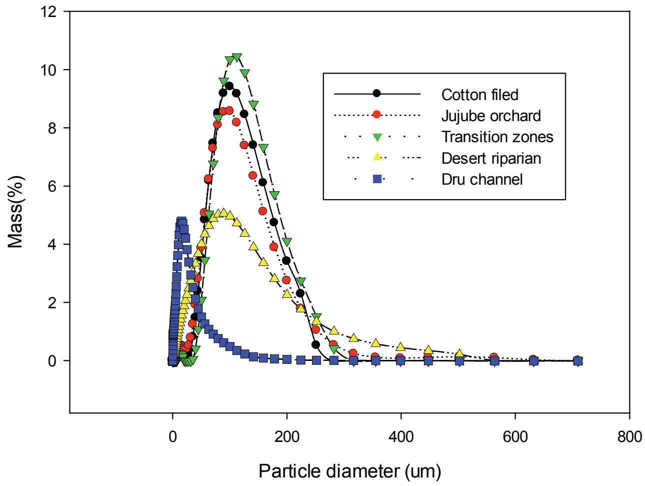

Figure 3: Dispersed particle size distribution of five soil types.

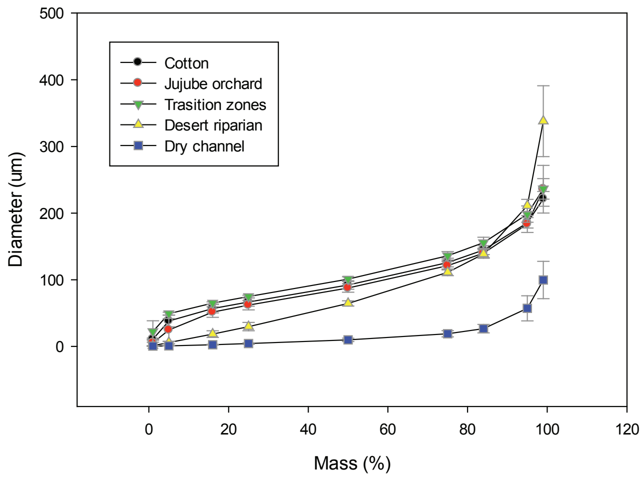

Figure 4: Dispersed particle size diameter distribution of five soil types.

that the soils had low clay content in whole study area. There was no significant difference in soil texture between Jujube orchard and cotton fields indicating that the cropping pattern had no significant effect on soil texture, especially for short-term.

The D50 and D95 represent the 50th and the 95th percentile of the particle size distribution, respectively, as measured by volume. The D50 and D95 had range from 9.78 um to 100.93 um, and 57.06 to 211.03 um, respectively. The Transition zone had highest D50 values, the dry channel the lowest. For D95, the Desert riparian had highest value, followed by the transition zone; the cotton field and the orchard had also high values. The Dry channel had lowest D95 (57.06 um), perhaps because of the fine sediment particle deposition.

The erodible fraction is usually defined as the mass fraction of aggregates <840 um in diameter. It is susceptible to erosion by the processes of suspension, saltation, and creep (Chepil 1941). The particles greater than 0.84mm were not found in any soil. Therefore, the soils erosion by wind in these types of land use should be considered.

Chepil (1955) observed a definite relationship between amounts of erosion in a wind tunnel and the clay content in the soil. Soils containing 20 to 35% clay were least erodible. Obviously, no soils in our study match this condition, and therefore high potential of wind erosion was possible in the five types of land use.

Saltation is responsible primarily for the redistribution of surface soil within the ecosystem and exerts influences on vegetation and soils at a local scale (Li *et al.* 2007; Okin *et al.* 2006). Mirzamostafa *et al.* (1998) performed separate calculations for the erosion of soil by suspension and saltation processes, both of which they predicted from dispersed soil analysis. It is logical to predict suspension-size material (<0.1mm) for eolian soils separately from saltation-sized material (0.1 mm to 0.84 mm). The content of saltation-sized material in our five treatments were 52.66 %, 48.59%, 60.68%, 32.05%, and 2.07%, respectively. The cotton field, orchard, transition zone and Desert riparian had high content of saltation-sized material. Especially in the transition zone, the content of saltation-sized material reached 60.68 %, indicating that the oasis-desert transition zone was important saltaion area, and the saltaion by wind should be of great concern in this area. The Dry channel had lowest content of such material (only 2.07%), and the saltation was not serious here. The order of content of saltation-sized material was as follows: Transition zone > cotton > Jujube orchard > Desert riparian > dry channel. There were no significant (P<0.01) differences among Transition zone, Cotton, Jujube orchard and Desert riparian (Table 3), indicating that saltation was serious problem in these four treatments.

Dust is defined here as a terrestrial sediment, sized<100μm which is transported in aeolian suspension (McTainsh and Strong 2007). The contents of suspension material in the five treatments (Fig. 5) were high (47.34 %, 51.41%, 39.32%, 64.95%, and 97.93%). The dry channel was very important source for dust suspension. The transition zone although had lowest percentage of suspension material (39.32%) it was still high enough for generating aeolian suspension. The rank of suspension material as follow: dry channel > Desert riparian > cotton > jujube orchard > transition zone. The results were contrary to the saltaion.

Table 3: Saltation and suspension; multiple comparisons among different treatments

Treatments	Treatments	Mean difference	Sig.	95% confidence interval	
				Upper	Lower
Cotton	Orchard	4.06	0.25	-3.36	11.49
	Transition zones	-8.02*	0.04	-15.44	-0.60
	Desert riparian	17.60*	0.00	10.18	25.03
	Dry channel	50.58*	0.00	43.16	58.01
Orchard	Cotton	-4.06	0.25	-11.49	3.36
	Transition zones	-12.08*	0.01	-19.51	-4.66
	Desert riparian	13.54*	0.00	6.11	20.96
	Dry channel	46.52*	0.00	39.10	53.94
Transition zones	Cotton	8.02*	0.04	0.60	15.44
	Orchard	12.08*	0.01	4.66	19.51
	Desert riparian	25.62*	0.00	18.20	33.05
	Dry channel	58.60*	0.00	51.18	66.03
Desert riparian	Cotton	-17.60*	0.00	-25.03	-10.18
	Orchard	-13.54*	0.00	-20.96	-6.11
	Transition zones	-25.62*	0.00	-33.05	-18.20
	Dry channel	32.98*	0.00	25.56	40.40
Dry channel	Cotton	-50.58*	0.00	-58.01	-43.16
	Orchard	-46.52*	0.00	-53.94	-39.10
	Transition zones	-58.60*	0.00	-66.03	-51.18
	Desert riparian	-32.98*	0.00	-40.40	-25.56

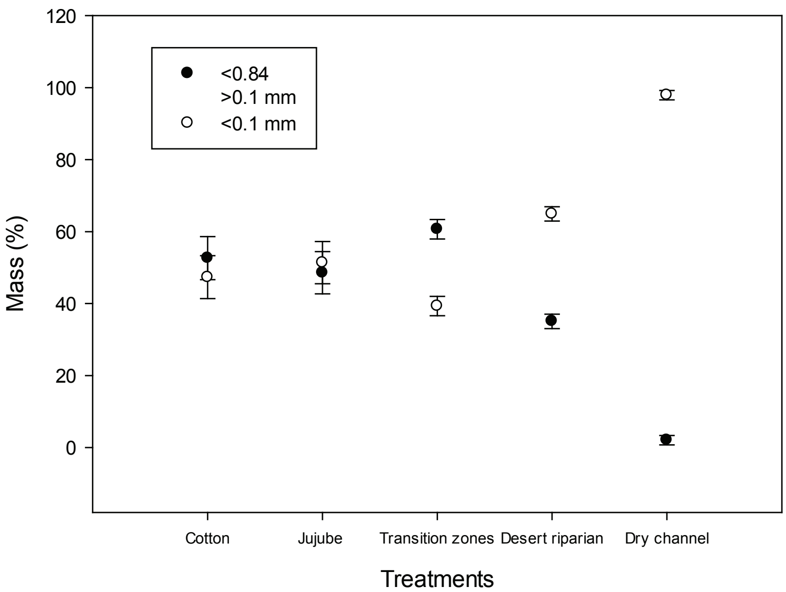

Figure 5: The saltation and suspensions content of five treatments

Table 4: PM10 content; multiple comparisons among different treatments

Treatments	Treatments	Mean difference	Sig.	95% confidence interval	
				Upper	Lower
Cotton	Orchard	-1.53	0.71	-10.39	7.33
	Trans. zones	0.56	0.89	-8.30	9.43
	Desert ripar.	-8.29	0.06	-17.16	0.57
	Dry channel	-51.04*	0.00	-59.90	-42.18
Orchard	Cotton	1.53	0.71	-7.33	10.39
	Trans. zones	2.09	0.61	-6.77	10.96
	Desert ripar.	-6.76	0.12	-15.63	2.10
	Dry channel	-49.51*	0.00	-58.37	-40.65
Trans. zones	Cotton	-0.56	0.89	-9.43	8.30
	Orchard	-2.09	0.61	-10.96	6.77
	Desert ripar.	-8.86	0.05	-17.72	0.01
	Dry channel	-51.60*	0.00	-60.47	-42.74
Desert ripar.	Cotton	8.29	0.06	-0.57	17.16
	Orchard	6.76	0.12	-2.10	15.63
	Trans. zones	8.86	0.05	-0.01	17.72
	Dry channel	-42.74*	0.00	-51.61	-33.88
Dry channel	Cotton	51.04*	0.00	42.18	59.90
	Orchard	49.51*	0.00	40.65	58.37
	Trans. zones	51.60*	0.00	42.74	60.47
	Desert ripar.	42.75*	0.00	33.88	51.61

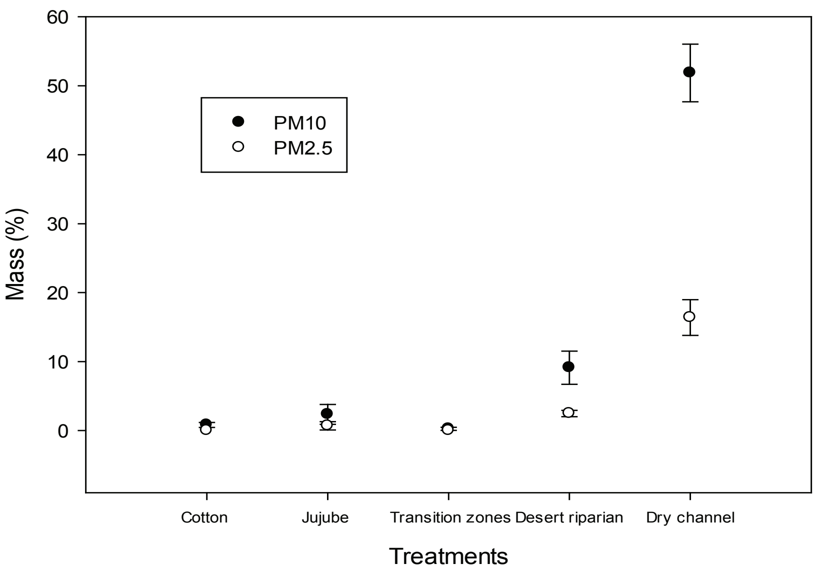

Figure 6: The PM2.5 and PM 10 content of five treatments.

Soil and mineral particles with a diameter <60 µm are especially important for air quality because they contain significant amounts of soil nutrients (Zobeck and Fryrear 1986) and contaminants. The results of the sieving analysis revealed that the particle content (<60um) of soils of five treatments were 15.88%, 19.91%, 9.23%, 44.27% and 95.10%, respectively. The dry channel and Desert riparian had high potential contribution to poor air quality, the transition zone had the lowest.

Of particular concern are the particles with a mean aerodynamic diameter less than or equal to 2.5 µm (PM2.5) and 10 µm (PM10) which are stringently monitored by the U.S. Environmental Protection Agency (EPA) as air pollutants. Figure 6 shows that cotton, jujube orchard and transition zones had low content of PM 10 and PM 2.5, the transition zones having the lowest value. The dry channel had significantly the highest content of PM 10 and PM 2.5 than others (Table 5). The dry channel had great potential contribution for PM 10 and PM 2.5 in Akesu area.

Table 5: PM 2.5 content; multiple comparisons among different treatments

Treatments	**Treatments**	**Mean difference**	**Sig.**	**95% confidence interval**	
				Up	**Low**
Cotton	Orchard	-0.69	0.63	-3.79	2.41
	Trans. zones	0.00	1.00	-3.10	3.10
	Desert ripar.	-2.47	0.11	-5.58	0.63
	Dry channel	-16.38*	0.00	-19.49	-13.28
Orchard	Cotton	0.69	0.63	-2.41	3.79
	Trans. zones	0.69	0.63	-2.41	3.79
	Desert ripar.	-1.78	0.23	-4.89	1.32
	Dry channel	-15.69*	0.00	-18.80	-12.59
Transitio zones	Cotton	0.00	1.00	-3.10	3.10
	Orchard	-.69	0.63	-3.79	2.41
	Desert ripar.	-2.47	0.11	-5.58	0.63
	Dry channel	-16.39*	0.00	-19.49	-13.28
Desert riparian	Cotton	2.47239	0.11	-0.63	5.58
	Orchard	1.78	0.23	-1.32	4.89
	Trans. zones	2.47	0.11	-0.63	5.58
	Dry channel	-13.92*	0.00	-17.02	-10.81
Dry channel	Cotton	16.39*	0.00	13.28	19.49
	Orchard	15.70*	0.00	12.59	18.80
	Trans. zones	16.39*	0.00	13.28	19.49
	Desert ripar.	13.92*	0.00	10.81	17.02

Thus, the dry channel has the largest potential contribution for PM10, PM2.5, suspension material and poor air quality; the Desert riparian follows. Therefore, these two types of land use must be of great concern for wind erosion. The wind season is concentrated form March to May, when the river is dry during. The Desert riparian and dry channel had low soil water content, which would be conducive for wind erosion. In addition, the soil surface of these two types of land use also was destroyed by livestock.

Conclusion

The five land use types tested in this study represent major land use pattern in the Akesu region. Except for Dry channel, soils in all land uses had high percentage of sand. There was no significant difference between Jujube orchard and cotton from size distribution point of view. For D95, the Desert riparian had highest value, the transition zone followed, the cotton and the orchard had also high values. The Dry channel had lowest D95. The particles greater than 0.84mm were not found in any soil, there was thus no nonerodible soil by wind in study area. The content of saltation was high in all the treatments except Dry channel. The five treatments had high suspension content, especially the dry channel. The dry channel also had highest content of PM 10 and PM 2.5, and the Desert riparian followed. Therefore, the dry channel and Desert riparian land use must be of great concern for wind erosion.

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Escalation of wind erosion from oilseed crops grown in the USA Pacific Northwest

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Abstract

The United States has a goal to produce 136 billion liters of biofuel by 2022 with 79 billion liters being derived from advanced biofuels. The Pacific Northwest is expected to produce about 5% of these advanced biofuels. Although progress is being made in growing oilseeds for advanced biofuels, little is known concerning the impact of growing oilseed crops on natural resources. The objective of this study was to examine the impact of growing oilseeds in conventional wheat-fallow rotations on wind erosion and PM10 (particles ≤10µm in diameter) emissions in Washington state where atmospheric PM10 is an acute environmental concern. Wind erosion and PM10 emissions were measured after sowing winter wheat into summer fallow of a winter wheat-summer fallow (WW-SF) rotation and a winter wheat-camelina-summer fallow (WW-C-SF) rotation or winter wheat-safflower-summer fallow (WW-S-SF) rotation. During the 13-month fallow phase of the rotation, the soil was cultivated once in spring and rodweeded prior to sowing winter wheat. A wind tunnel was used to assess horizontal sediment and PM10 flux after sowing wheat (period of the rotation most susceptible to erosion). Sediment and PM10 flux were as much as a 250% higher after sowing winter wheat in the WW-C-SF and WW-S-SF rotations compared with the WW-SF rotation. Less surface biomass following the oilseed crop likely contributed to the higher sediment and PM10 flux from the WW-C-SF and WW-S-SF rotations. Our results suggest that wind erosion and PM10 emissions are accentuated after sowing winter wheat in WW-C-SF and WW-S-SF rotations as compared with the traditional WW-SF rotation. Further research is required to assess life cycle analysis of emissions during the fallow phase of the rotations because less frequent use of summer fallow in the WW-C-SF and WW-S-SF rotations may compensate for higher emissions after sowing wheat in these rotations than the WW-SF rotation.

Introduction

Petroleum oil is the lifeblood of the transportation industry in many parts of the world. In an effort to reduce petroleum oil consumption, the United States has advocated the development of renewable energy sources since the creation of the Department of Energy in 1977. In fact, the Energy Independence and Security Act of 2007 mandates the use of 136 billion liters of biofuel in the transportation industry by 2022. Of this, 57 billion liters is required to come from cornstarch feedstock while 79 billion liters must come from advanced biofuel derived using non-cornstarch feedstock such as sugar, cellulosic, or waste material. To meet this goal, the United States Department of Agriculture (USDA) recently developed a strategy entitled "A USDA regional roadmap to meeting the biofuels goals of the Renewable Fuels Standard by 2022" in which 49.8% of the advanced biofuel would be produced in the southeast, 43.3 % in the central, 4.6% in the northwest, 2.0% in the northeast, and 0.3% in the southwest regions of the United States (USDA, 2010).

A large fraction of biofuel to be produced in the western United States is anticipated to come from oilseeds grown on arid and semi-arid agricultural lands. Oilseeds, however, are not currently grown across extensive areas of the region. Oilseed crops such as canola and sunflower have been grown with success in the western United States, but their widespread absence from cropping systems is a result of small or niche markets. Other drought-tolerant oilseed crops such as camelina and safflower have the potential of being grown in the western United States. Adoption to the region, however, will require agronomic and rotational practices that are as profitable as current cropping systems and protect environmental resources.

Air quality is a major environmental concern across the Columbia Plateau of the Inland Pacific Northwest. The low precipitation zone, delineated by <300 mm of annual precipitation, of the Columbia Plateau is particularly susceptible to wind erosion due to the occurrence of high winds, poorly-aggregated soils, and low biomass production. Winter wheat-summer fallow (WW-SF) is the conventional crop rotation used on more than 1.5 million hectares in the low precipitation zone. Wind erosion occurs primarily during the fallow phase of the rotation and is particularly acute at the end of the fallow phase when the soil is most exposed to the forces exerted by the wind. Soils in the region are mainly of loessial origin and contain a large fraction of fine particulate matter. Particulate matter ≤10 um in diameter (PM10) is emitted in the atmosphere during high wind events and occasionally results in exceedance of PM10 air quality standards in communities downwind of eroding agricultural lands (Sharratt and Lauer 2006).

The impact of growing oilseeds in conventional cropping systems on wind erosion is unknown across the western United States, including the Columbia Plateau region. The purpose of this study was to examine the effect of growing oilseeds in traditional crop rotations on wind erosion and PM10 emissions from agricultural soils.

Materials and methods

The potential for wind erosion and PM10 emissions from oilseed crop rotations in the Columbia Plateau was assessed in 2011 and 2012 at Lind and Ritzville, Washington (Fig. 1). The conventional crop rotation used at both locations is WW-SF. The fallow phase of the rotation typically begins after harvest in July and continues until sowing winter wheat the following August. Average annual precipitation at Lind is 240 mm and at Ritzville is 260 mm. The soil at both locations is a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxeroll according to USDA taxonomy).

Crop rotations

Wind erosion was assessed from a WW-SF rotation and a winter wheat-camelina-summer fallow (WW-C-SF) rotation at Lind. Winter wheat is sown in August and harvested the following July. The fallow phase of the rotation lasts about 13 months. Camelina is sown in March and harvested in July and was included in the rotation due to interest as a potential bioenergy crop by the agricultural and transportation industries. Camelina seed contains about 35% oil, 35% linolenic acid, and 3% erucic acid. The relatively high erucic acid content is an undesirable characteristic for human consumption. Camelina meal can be fed to animals due to the low glycosinolate content (20 mmol kg^{-1}).

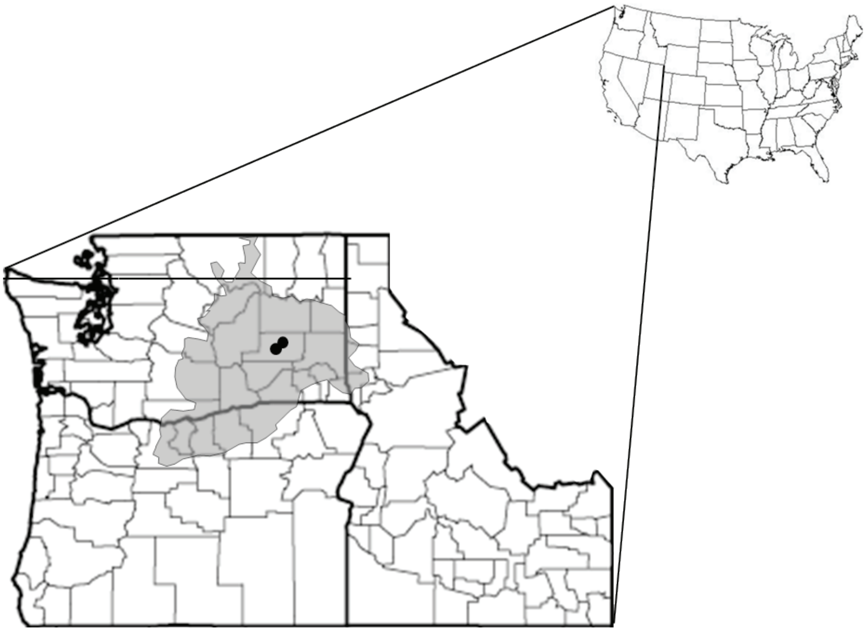

Figure 1: Locations (black dots) in the Columbia Plateau (shaded area) where wind erosion was measured in winter wheat-summer fallow and winter wheat-camelina-summer fallow or winter wheat-safflower-summer fallow rotations.

Winter wheat (in the WW-SF rotation) and camelina (in the WW-C-SF rotation) were harvested in July 2010 and 2011. The soil remained undisturbed after harvest until the following spring (April) when the soil was cultivated with an undercutter implement. The undercutter is a low disturbance, non-inversion tillage implement with 0.8-m wide sweeps. The soil was rodweeded in June and July prior to sowing winter wheat in both rotations on 2 September 2011 and 28 August 2012.

The crop rotations included in our assessment of wind erosion at Ritzville was a WW-SF rotation and a winter wheat-safflower-summer fallow (WW-S-SF) rotation. Safflower is sown in May and harvest in July and was included in the rotation because of interest as a potential bioenergy crop. Safflower produces seed enriched in linoleic acid (about 85%) and low in erucic acid (0%), both of which are desirable for human consumption. The oil content of safflower seed is about 25% and the meal can be used as an animal feed due to its low glycosinolate content (20 mmol kg^{-1}). The deep taproot allows safflower to access nutrients and water lower in the soil profile that would otherwise be unavailable to shallow-rooted crops.

After harvest of winter wheat (in the WW-SF rotation) and safflower (in the WW-S-SF rotation) in July 2010 and 2011, the soil remained undisturbed after harvest until the soil was cultivated with an undercutter implement the following spring (May). The soil was rodweeded in July prior to sowing winter wheat in both rotations on 8 September 2011 and 11 September 2012.

The crop rotations were established in a randomized complete block design with four replications at Lind in 2008 and at Ritzville in 2009. Individual plots were 9 x 150 m and all phases of each rotation were present every year. Wind erosion was assessed using a portable wind tunnel on 14 September 2011 and 30 August 2012 at Lind and on 20 September 2011 and 11 September 2012 at Ritzville.

Wind tunnel

Wind erosion was assessed after sowing winter wheat at both locations because the soil is most vulnerable to erosion during this time in the rotation. Although wind erosion assessments were delayed 12 days after sowing wheat at both locations in 2011, no precipitation occurred during this delay. Wind erosion assessments at Ritzville were delayed two days after sowing wheat in 2011; during this delay, a 0.5-mm precipitation event resulted in the development of a very thin (<0.5 mm) and weak (<15 kPa), but perceivable soil crust.

Wind erosion and PM10 emissions from the crop rotations were assessed using a portable wind tunnel. The working section of the wind tunnel is 7.3-m long, 1.2-m tall, and 1.0-m wide. Wind is generated by a 1.4-m diameter fan and is conditioned by passing through a diffuser, honeycomb-screen, and grid assembly before entering the working section of the tunnel. The conditioning process is used to achieve shear flow characteristics similar to those that occur naturally in the field (Pietersma *et al*. 1996; Sharratt 2007).

Horizontal sediment flux and PM10 concentrations were observed within the working section of the tunnel. Horizontal sediment flux was measured using a Bagnold-type slot sampler (Stetler *et al.* 1997) that catches sediment being transported by saltation and suspension within 0.75 m of the surface. The width of the opening of the sampler was adjusted to achieve isokinetic conditions across the face of the sampler at a free-stream wind velocity of 15 m s^{-1}. This wind speed, which was maintained in the wind tunnel, typifies a sustained high wind event that occurs about every 2 years in the Columbia Plateau region (Wantz and Sinclair 1981). Horizontal sediment flux is the mass of sediment moving across a vertical plane over a period of time and was determined as the ratio of sediment collected by the slot sampler to the sampling period and width of the sampler (~0.003 m). PM10 concentrations were measured at a frequency of 1 Hz using factory-calibrated DustTrak aerosol monitors (TSI, St. Paul, MN). Monitor inlets were mounted at heights of 0.04, 0.06, 0.09, 0.15, 0.30, and 0.60 m above the surface. These inlets were constructed of stainless steel tubing and of a diameter to achieve isokinetic sampling of PM10 at a height of 0.2 m within the wind tunnel. Aerosol monitor inlets at greater heights would undersample PM10 concentrations while monitor inlets at lower heights would oversample PM10 concentrations. No adjustments were made to account for differences in sampling efficiency of monitors with height. Background PM10 concentration was measured at the leading edge of the working section of the tunnel. Pitot tubes were mounted adjacent to and at heights corresponding to aerosol monitor inlets to measure the wind speed. Ambient air temperature, relative humidity, and atmospheric pressure were measured at a height of 1.5 m outside the wind tunnel to aid in computing wind speed.

Horizontal sediment flux and PM10 concentrations were measured over two subsequent sampling periods in each experimental plot. The first sampling period represents field conditions with limited saltation. To avoid exceeding aerosol monitor capabilities at startup, free-stream wind speed was maintained at ~10 m s^{-1} for the first three minutes and then at ~15 m s^{-1} for the last seven minutes of the first sampling period. The lower wind velocity at startup allowed for the removal of perched particles from the soil surface. The second sampling period, which lasted seven minutes, was characterized by a free-stream wind speed of ~15 m s^{-1} and field conditions with active saltation. Saltation activity that mimics field conditions was achieved by introducing an abrader (quartz sand 250-500 μm in diameter) into the air stream at the leading edge of working section at a rate of 0.5 g m^{-1} s^{-1}. This abrader rate is representative of soil flux during extreme high winds in the Columbia Plateau (Sharratt *et al.* 2007).

Aerodynamic parameters and PM10 flux

Wind speed and PM10 concentrations were measured within and above the boundary layer and parallel to and between crop rows. It was assumed that wind speed in the internal boundary layer was fully adjusted to the surface and a logarithmic relationship was applied to wind speed and height according to Campbell and Norman (1998):

$$U(z) = (u^*/\mathrm{k})\ln[(z)/z_o] \qquad (1)$$

where $U(z)$ is mean wind speed (m s^{-1}) at height z (m), k is the von Karman constant (0.4), u^* is friction velocity (m s^{-1}), and z_o is roughness parameter (m). Friction velocity and z_o were determined by plotting the natural log of (z) against $U(z)$. To determine u^*, three to four heights within the boundary layer were used for best-fit linear regression. A high degree of linearity (R^2>0.95) ensured that measurements were made in the boundary layer.

Horizontal PM10 flux was calculated as:

$$PM10_{hf} = \int Cu\,\mathrm{d}z \qquad (2)$$

where $PM10_{hf}$ is horizontal PM10 flux (g m^{-2} s^{-1}), C is PM10 concentration above background concentration (g m^{-3}), and the integral is evaluated from the surface to the height at which PM10 concentrations reached background concentrations.

Surface characteristics

In conjunction with assessing sediment flux and $PM10_{hf}$ from the experimental plots, soil properties and surface residue characteristics were measured at three locations adjacent to the wind tunnel. In these proceedings, we only consider surface crop residue characteristics important in wind erosion. These characteristics aided in interpreting differences in sediment flux and $PM10_{hf}$ between treatments.

Statistical analysis

Analysis of variance (ANOVA) was used to analyze differences in horizontal sediment flux, $PM10_{hf}$, and surface characteristics of cropping systems. The sediment and PM10 data collected at Lind in 2011 and at Ritzville in 2012 required transformation prior to analysis due to heterogeneity of variance. Means were considered significantly different at P<0.10.

Results and discussion

The loessial soils in the low precipitation zone of the Columbia Plateau are susceptible to wind erosion due to low biomass production and poorly-aggregated and fragile soils. These soils contain a high percentage of fine particles, with PM10 and silt contents as high as respectively

40 and 65% (Sharratt and Vaddella 2012). Conventional tillage, despite partially inverting the soil and burying considerable surface residue and thereby exposing the soil surface to the forces of wind, creates a friable soil that conserves seed-zone moisture during the fallow phase of the rotation (Singh *et al.* 2011). Wind erosion was assessed immediately after sowing winter wheat when the soil is most vulnerable to erosion.

Wind speed increased logarithmically while PM10 concentration decreased as a power function of height inside the wind tunnel. Differences were apparent in the wind speed and PM10 concentration profiles between the rotational treatments as illustrated for a single replication of the WW-SF and WW-C-SF rotations at Lind (Fig. 2) and the WW-SF and WW-S-SF rotations at Ritzville in 2011 (Fig. 3). Differences in wind speed and PM10 concentration between rotational treatments were not apparent above approximately 0.3 m, but were more apparent nearer the soil surface.

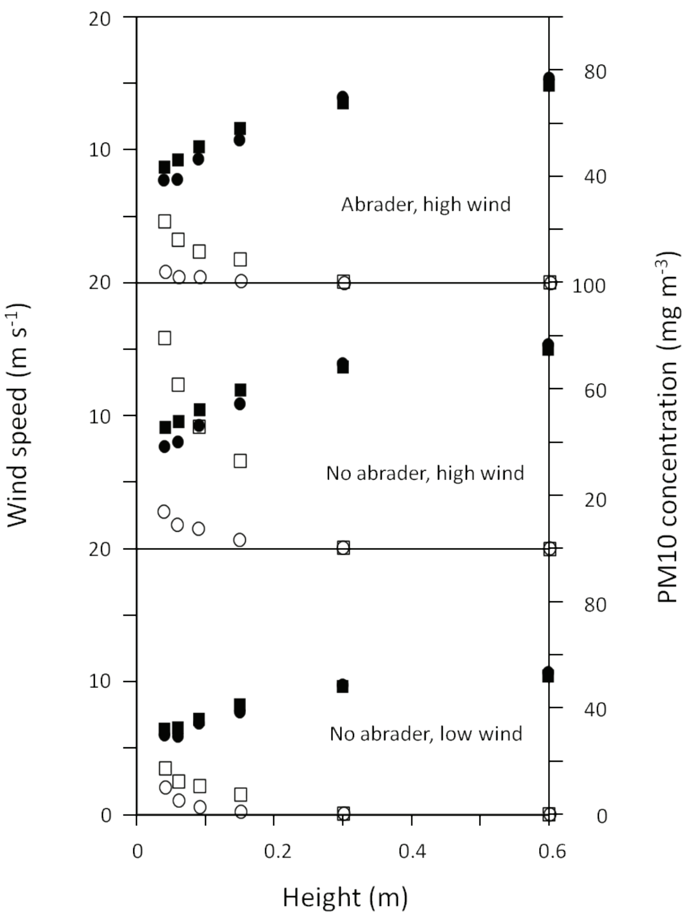

Figure 2: Wind speed (solid symbols) and PM10 concentration (open symbols) measured at various heights inside a wind tunnel after sowing winter wheat into a winter wheat-summer fallow (circles) and winter wheat-camelina-summer fallow rotation (squares) at Lind, Washington in 2011. Wind speed and PM10 concentration were measured over two subsequent sampling periods; the first period with initially low wind speed followed by high wind speed under conditions of limited saltation (no abrader added to the air steam) and the second period with high wind speed under conditions of copious saltation (abrader added to the air steam).

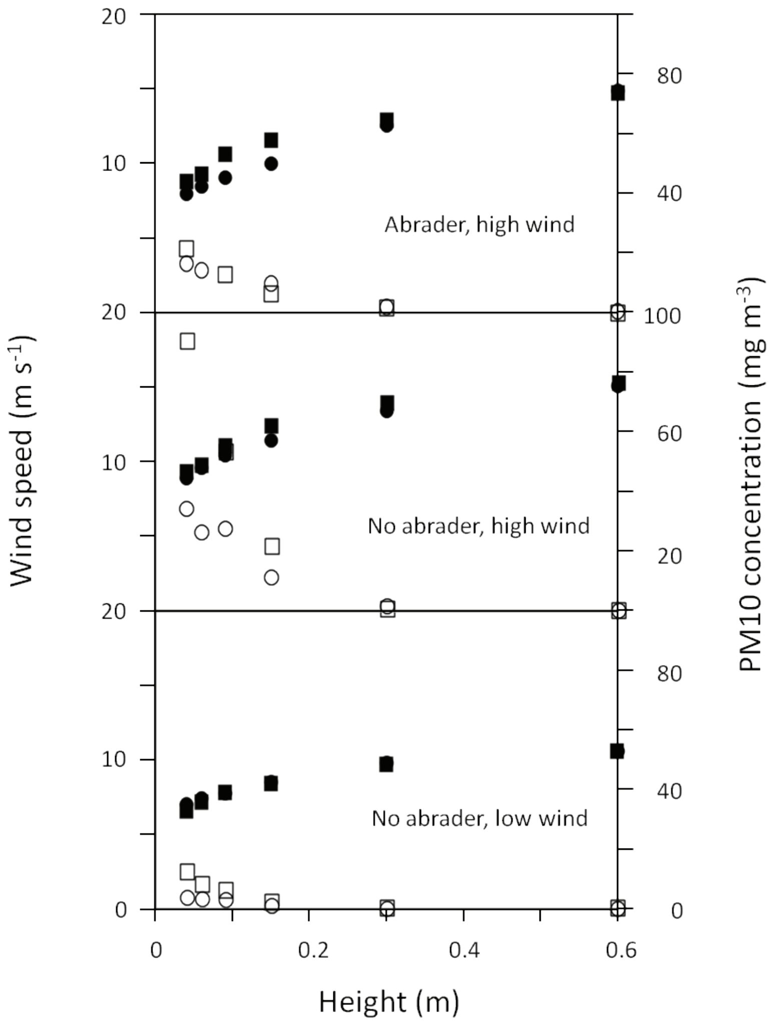

Figure 3: Same as Fig. 2 except wind speed (solid symbols) and PM10 concentration (open symbols) were measured at various heights inside a wind tunnel after sowing winter wheat into a winter wheat-summer fallow (circles) and winter wheat-safflower-summer fallow rotation (squares) at Ritzville, Washington in 2011.

Horizontal sediment flux at Lind appeared to be lower in 2011 than in 2012 (Table 1) even though a thin and weak soil crust was present in 2012. This crust developed as a result of a 0.5-mm precipitation event which occurred on the day of sowing. The lower sediment flux in 2011 was likely due to the establishment of wheat prior to our assessment of wind erosion in 2011. Wheat was about 100-mm tall with a leaf area index of 0.02 m^2 m^{-2} when we assessed erosion at Lind in 2011. Although crop residue and soil moisture are important factors which affect erosion, little difference was observed in crop residue biomass on the soil surface (Table 2) or in water potential of soil across years at Lind. Sediment flux at Ritzville was similar in 2011 and 2012 despite crop residue biomass on the soil surface being 200% greater in 2012 than in 2011. Sediment flux was not affected by soil moisture as little difference was observed in soil water potential across years. Establishment of wheat likely compensated for the lower residue biomass in 2011, resulting in similar sediment flux at Ritzville across years. Wheat was about 100-mm tall with a leaf area index of 0.01 m^2 m^{-2} when wind erosion was assessed in 2011.

Table 1: Horizontal sediment flux measured after sowing winter wheat into summer fallow of a winter wheat-summer fallow and winter wheat-camelina-summer fallow rotation at Lind, Washington and a winter wheat-summer fallow and winter wheat-safflower-summer fallow rotation at Ritzville, Washington

		Sediment flux (g m^{-1} min^{-1})[1]			
		Without abrader		With abrader	
Location	Year	Wheat	Oilseed[2]	Wheat	Oilseed
Lind	2011	75a[3]	256b	62a	146b
	2012	340a	804b	281a	587a
Ritzville	2011	376a	778b	311a	569b
	2012	338a	615a	196a	653b

[1] Horizonatal sediment flux measured over two consecutive 10 minute sampling periods; the first period without abrader and the second period with abrader added to the air stream.

[2] Oilseed at Lind was camelina and at Ritzville was safflower.

[3] No abrader or abrader means followed by the same letter at same location and year are not significantly different at P=0.10.

Horizontal sediment flux was greater after sowing wheat into summer fallow in the WW-C-SF or WW-S-SF rotation than the WW-SF rotation in 2011. Although similar results were obtained in 2012, sediment flux did not differ between treatments under conditions of limited saltation (without abrader) at Ritzville and under conditions of copious saltation (with abrader) at Lind. In 2011, sediment flux was 83 to 241% greater for the winter wheat-oilseed-summer fallow rotations than the WW-SF rotation. In 2012, sediment flux was 0 to 233% greater for the winter wheat-oilseed-summer fallow rotations than the WW-SF rotation.

The lower sediment flux in the WW-SF rotation may be due to greater crop residue biomass or cover on the soil surface after sowing wheat into summer fallow as compared with the WW-C-SF or WW-S-SF rotation. Residue biomass was 0 to 503% higher in the WW-SF rotation than the winter wheat-oilseed-summer fallow rotations across locations and years (Table 2). In addition, residue cover was 0 to 333% higher in the WW-SF rotation than the winter wheat-oilseed-summer fallow rotations across locations and years.

Similar to horizontal sediment flux, $PM10_{hf}$ was generally greater from the WW-C-SF and WW-S-SF rotations than from the WW-SF rotation (Table 3). In 2011, $PM10_{hf}$ was 0 to 253% higher from the winter wheat-oilseed-summer fallow rotations than the WW-SF rotation across locations. No difference in $PM10_{hf}$ was observed under conditions of copious saltation at Ritzville. Analysis of $PM10_{hf}$ is yet incomplete for 2012.

The ratio of $PM10_{hf}$ to horizontal sediment flux did not differ between rotational treatments at both locations in 2011 (Table 4). The ratio varied from 0.009 to 0.018 across treatments; these ratios are similar to observations made previously for various tillage management practices at Lind. For example, Sharratt *et al.* (2010) found that the ratio of $PM10_{hf}$ to sediment flux varied from 0.006 to 0.226 across a range of tillage practices during the summer fallow phase of a WW-SF rotation. The lack of response in the ratio of $PM10_{hf}$ to sediment flux between the crop rotations examined in this study suggests that an oilseed crop in the conventional WW-SF rotation has no effect on aggregation of the small particle size (≤10 μm) fraction. However, an oilseed crop in the rotation appeared to influence the mass of material on the soil surface susceptible to erosion. The greater susceptibility of the WW-C-SF and WW-S-SF rotations to erosion may be due to greater exposure of the soil surface to the forces of wind than the WW-SF rotation.

Table 2: Surface crop residue characteristics measured after sowing winter wheat into summer fallow of a winter wheat-summer fallow and winter wheat-camelina-summer fallow rotation at Lind, Washington and a winter wheat-summer fallow and winter wheat-safflower-summer fallow rotation at Ritzville, Washington

		Total residue (kg ha^{-1})		Residue cover (%)		Stem area index (m^2 m^{-2})	
Location	**Year**	**Wheat**	**Oilseed[1]**	**Wheat**	**Oilseed**	**Wheat**	**Oilseed**
Lind	2011	1435a[2]	238b	27a	27a	0.007a	0.001b
	2012	904a	772a	20a	11b	0.003a	0.002a
Ritzville	2011	965a	766a	26a	6b	0.007a	0.006a
	2012	4874a	1544b	46a	16b	0.002a	0.001a

[1] Oilseed at Lind was camelina and at Ritzville was safflower; [2] Means of residue characteristics followed by the same letter at same location and year are not significantly different at P=0.10.

Table 3: Horizontal PM10 flux measured after sowing winter wheat into summer fallow of a winter wheat-summer fallow and winter wheat-camelina-summer fallow rotation at Lind, Washington and a winter wheat-summer fallow and winter wheat-safflower-summer fallow rotation at Ritzville, Washington

		PM10 flux (g m^{-1} min^{-1})[1]			
		Without abrader		**With abrader**	
Location	**Year**	**Wheat**	**Oilseed[2]**	**Wheat**	**Oilseed**
Lind	2011	0.91a[3]	3.06b	0.49a	1.73b
	2012	ND[4]	ND	ND	ND
Ritzville	2011	4.19a	10.29b	3.80a	5.15a
	2012	ND	ND	ND	ND

[1] Horizontal PM10 flux measured over two consecutive 10 minute sampling periods; the first period without abrader and the second period with abrader added to the air stream; [2] Oilseed at Lind was camelina and at Ritzville was safflower; [3] No abrader or abrader means followed by the same letter at same location and year are not significantly different at P=0.10; [4] Not determined.

Table 4: Ratio of horizontal PM10 flux to sediment flux measured after sowing winter wheat into summer fallow of a winter wheat-summer fallow and winter wheat-camelina-summer fallow rotation at Lind, Washington and a winter wheat-summer fallow and winter wheat-safflower-summer fallow rotation at Ritzville, Washington

		Ratio[1]			
		Without abrader		**With abrader**	
Location	**Year**	**Wheat**	**Oilseed[2]**	**Wheat**	**Oilseed**
Lind	2011	.018a[3]	.019a	.009a	.014a
	2012	ND[4]	ND	ND	ND
Ritzville	2011	.010a	.013a	.014a	.009a
	2012	ND	ND	ND	ND

[1] Ratio of horizontal PM10 flux to sediment flux measured over two consecutive 10 minute sampling periods; the first period without abrader and the second period with abrader added to the air stream; [2] Oilseed at Lind was camelina and at Ritzville was safflower; [3] No abrader or abrader means followed by the same letter at same location and year are not significantly different at P=0.10; [4] Not determined.

Conclusions

Sediment and PM10 flux were higher after sowing winter wheat in the WW-C-SF and WW-C-SF rotations than the traditional WW-SF rotation used in eastern Washington State. The higher flux may be attributed in part to lower crop residue biomass or cover on the soil surface after sowing wheat into summer fallow of the WW-C-SF and WW-S-SF rotations as compared with the WW-SF rotation. While sediment and PM10 flux were measured only after sowing winter wheat into summer fallow, which is the time the soil is most susceptible to wind erosion during each rotation, the soil is also susceptible to erosion at other times during the summer fallow phase of the rotations. Disturbance of the soil and partial burial of surface crop residue after primary tillage in spring greatly accentuates the susceptibility of the soil to wind erosion that persists through the summer fallow phase of the rotation until wheat is established in late summer. Therefore, to assess the overall impact of growing oilseeds in traditional WW-SF rotations on wind erosion and PM10 emissions, an assessment is required of life cycle analysis of emissions during the fallow phase of each rotation because less frequent use of summer fallow in the WW-C-SF and WW-S-SF rotations may compensate for higher emissions after sowing wheat in these rotations as compared with the WW-SF rotation.

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Spatial variability of soil seed banks in the active sand dune systems in semi-arid region, China

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Abstract

The soil seed banks may provide a mechanistic understanding of recruitment dynamics and inform conservation management for the ecosystems. To assess the potential contribution of soil seed banks to vegetation restoration in active sand dune systems, comparisons of average seed density and similarity between soil seed bank and standing vegetation among active sand dunes, ecotones and interdune lowlands were made in Horqin Sandy Land, China. The results showed that average seed density in interdune lowlands was larger than ecotones and active sand dunes. The seed density in the soil layer of 0-10 cm was greater than 10-20 cm both in the active sand dunes and the ecotones, but there was no significant difference between the layer of 10-20 cm and 20-30 cm in the active sand dunes. Moreover, the spatial autocorrelation of the seed density on the active sand dunes was week, whereas strong on the ectones and interdune lowlands. Compositional similarity between soil seed bank and the standing vegetation was greater in the ecotones than the active sand dunes, but not higher than the interdune lowlands. Consequently, vegetation restoration can nott mainly rely on the soil seed bank on the active sand dunes, and more attention should paid to the interdune lowlands protection because they are the main source of seed dispersal and seedlings recruitment in active sand dune systems.

Introduction

Degradation in drylands regions around the world is affected by rapid change in vegetation cover, plant community composition, hydrological conditions, or soil properties. It is one of the major environmental issues of the twenty-first century because it results in a persistent loss of ecosystem services and poses serious threats to sustainable life (Ravi *et al.* 2010; D'Odorico *et al.* 2012). Thus, many countries have made great efforts to control desertification by planting and fencing to vegetation restoration (Zhang *et al.* 2005).

The process of vegetation restoration on desertified land can be viewed as succession (Zhang *et al.* 2005). Soil seed bank is the critical property of plant communities and is of considerable significance in the study of succession, since it plays prominent ecological and evolutionary roles in linking the past, present, and future plant population and community structure and dynamics in a given habitat (Thompson and Grime 1979; Bai *et al.* 2004; Yan *et al.* 2005). The soil seed banks are especially important in dunes ecosystems because the spatial variability of soil seed bank has a direct effect on the dynamics, conservation and sustainable management of the ecosystems (Bertiller 1998; Bai *et al.* 2004□Li *et al.* 2004). The high degree of spatial heterogeneity in structural and compositional properties of soil seed banks from arid and semiarid environments is mainly driven by patch scale heterogeneity in vegetation cover (Dreber and Esler 2011). If there is a disturbance to the plant community, such as desertification, the seed bank may help in reestablishing the original community. Thus, knowledge of the seed bank and an understanding of the population dynamics of buried viable seeds are of practical importance in vegetation regeneration (Li *et al.* 2004).

A good understanding of the soil seed bank on the active sand dune systems is critical for elucidating the mechanisms of vegetation persistence through harsh seasons and supply of propagules for re-establishment after disturbance (Lunt 1997; Auld *et al.* 2000; Sternberg *et al.* 2004), and mitigating the risk of species extinction on sand dunes (Wang and Liang 1995; Yan *et al.* 2009). Furthermore, the degree of correlation between the species composition of the seed bank and that of the associated plant community is of considerable interest in restoration projects (De Villiers *et al.* 2003; Ma *et al.* 2012). Examining the similarity between the seed bank and standing vegetation during succession may provide some new insights into the mechanisms of the resilience of a system, the drivers of community structure, and restoration strategies (Scott and Morgan 2012).

Windward slope of an active dune, interdune lowland or dune slack, and ecotone between the active sand dune and the lowland are the three parts of an active sand dune system (Yan *et al.* 2005; 2009). Active sand dunes are usually characterized by small moisture content, strong wind erosion, and sand burial, with coverage of less than 5% and advancement at a rate of 5 m to 7 m per year (Cao *et al.* 2004; Yan *et al.* 2005). The ecotone located at the foot of the windward slope of the dune is colonized by pioneering species such as *S. viridis*, *Phragmites communis, Hedysarum fruticosum* (Jiang *et al.* 2013). The interdune lowlands surrounded by crescent dunes serve as ‘‘vegetation islands’’, composed of psammophytes and nonpsammophytes and have a good soil moisture content (Yan *et al.* 2005; Liu *et al.* 2007).

The objectives of this study were to investigate the spatial variability of soil seed bank in active sand dune systems horizontally and vertically, and to investigate the contribution of soil seed bank to vegetation restoration and seedling recruitment in active sand dune systems through the similarity between the soil seed bank and standing vegetation.

Materials and methods

Study site

The study was conducted at Wulanaodu Experimental Station (119°39′-120°02′ E, 42°29′–43°06′ N), Chinese Academy of Sciences, northeastern Inner Mongolia, China, located at the western Horqin Sandy land. The climate is continental semiarid monsoon with mean precipitation of approximately 284 mm, 70% occurring in the summer (June-August). The mean annual air temperature is about 6.3 ºC. The lowest, -14.0 ºC, occurs in January and the highest, 23.0 ºC, occurs in July. The mean annual wind speed is 4.4 m s^{-1}, and the number of gale days (>16 m s^{-1}) is 21-80 days.

Sampling

Soil seed bank samples were taken from active sand dune systems in early April 2012 before spring germination and seed set after natural winter stratification. A 50 m × 50 m sampling plot was selected on the active sand dunes, ectones and interdune lowlands of three active sand dune systems, selected randomly. The 50 m × 50 m sampling plot was separated into 10 transects at an interval of 5 m. Ten cores, 5 m spaced, were collected at each transect. Each soil sample was collected using a cylindrical auger with 7 cm in diameter and 10 cm in length in three soil layers (0-10 cm, 10-20 cm and 20-30 cm) in the active sand dunes, two soil layers (0-10 cm and 10-20 cm) in ecotones, and one layer (0-10 cm) in interdune lowlands. A total of 1, 800 plots were sampled. Seedling emergence method was used to assess the composition of seed banks. In August 2012, vegetation compositions were investigated in 1 m × 1 m quadrats corresponding to soil seed banks cores when vegetation was well developed.

Data analysis

Differences between average seed density of three soil layers at active sand dune, two layers at ecotone, and three parts of active sand dune systems were assessed by one-way ANOVA and a Duncan test. Prior to this, homogeneity of variance was tested with a Levene's test. Differences obtained at a level of $P < 0.05$ were considered significant. The analysis used SPSS statistical package for windows.

The 3D bars of the average density on three of the active sand dunes, ecotones and interdune lowlands were done with Origin 8.0. In addition, the semivariances (Jiang *et al.* 2013) of the average density on the three of the active sand dunes, the ecotones and the interdune lowlands were calculated by GS+ (Gamma design software, version 9.0), and the semivariograms were generated. The semivariograms were plotted semivariance against lag distance, typically increasing from a theoretical Y-intercept of zero (the 'nugget'), and leveling off at the maximum semivariance (the 'sill'), which occurs at and beyond a particular lag distance (the 'range'). The ratio of the nugget effect to the sill is referred to as the relative nugget effect; it can be used to evaluate sampling error and short-scale spatial effect.

Similarity in species composition between each standing vegetation plot and the nearest seed bank plot(s) (n = 56 in spring and 64 in autumn) of 0 - 10 cm layer, was calculated using Sorensen's qualitative similarity index ($Cs = 2j/(a+b)$, where a is the total number of species in the seed bank, b is the total number of species in the vegetation and j is the total number in both the seed bank and the vegetation).

Results

There were 4, 12, and 16 species (Table 1) recorded in the soil seed banks of the active sand dunes, the ecotones, and the interdune lowlands, respectively, and 18 species of 7 families in total.

The average seed bank density at the soil layer 0-10 cm of the active sand dunes and of the ectones were 713 ± 158 seeds m^{-2} and 3, 554 ± 405 seed m^{-2}, respectively (Fig. 1). The seed density at the layer of 0-10 cm of the interdune lowlands was significant higher than that of the ectones and of the active sand dunes. Moreover, on the active sand dunes, the seed density at the soil layer of 0-10 cm was significant higher than 10-20 cm and 20-30 cm. Significant difference was also found at the soil layer of 0-10 cm and of 10-20 cm in the ectones.

In addition, the average seed density varied along the slope from the top of the active sand dunes to the bottom of the interdune lowlands (Fig. 2). The average seed density was lowest on the active sand dunes, and there were nearly no significant variations. However, the average seed density on the ecotones increased gradually along the slope. The differences occurred on the interdune lowland because the average seed density gradually increased to the highest value, then declined slightly.

Most values of the seed density on the active sand dunes (Fig. 3) were low except some particular high values, whereas the seed density on the interdune lowlands was high. The seed density of the ecotones at the side of the active sand dunes was lower than the other side. The semi-variance analysis of seed density on the active sand dunes showed that the spatial variability of soil seed bank on the active sand dunes could be fitted with the linear model. Both of the nugget variance and sill of the average seed density on the active sand dunes were 1.9 million. However, the spatial variability of soil seed bank on the ecotones and on the interdune lowlands fitted well with the exponential models. The nugget variances on the ecotones and interdune lowlands were 50,000 and 8.7 million, and sills were 13.76 million and 66.42 million, respectively. Both of the soil seed banks on the ecotones and interdune lowlands showed high heterogeneity.

Calculation of Sorensen's index indicated 13.30 %, 15.66 %, and 29.76 % similarity between vegetation and the soil seed bank of the active sand dunes, the ecotones, and the interdune lowland, respectively (Fig. 4). Moreover, the similarity on the interdune lowlands was higher than that on the ecotones and the active sand dunes significantly.

Discussion

Contribution of abiotic and biotic factors to the soil seed bank

Soil seed banks can be important sources for restoration of species-rich vegetation, high seed densities and a high number of species contribute to a potential role of the seed bank in vegetation development during restoration (Bakker *et al.* 1996). The comparison of the soil seed banks in the active sand dune systems revealed that the interdune lowlands were characterized by higher seed density than the ecotones and the active sand dunes at the layer of 0-10 cm, and the active sand dunes had the lowest seed density. Moreover, seed density on the active sand dunes was highest in the upper 10 cm of the soil and generally declined with depth, and the seed density of the upper 10 cm on the ecotones was higher than 10 – 20 cm. Seed densities on the active sand dunes and ecotones showed a declining trend from the upper to the deeper soil levels. The C0/(C0+C) of the upper layer seed density on the active sand dunes was nearly 100%, and the nugget variance and sill indicated that nearly 100% of heterogeneity of the soil seed bank on the active sand dunes came from random factors. However, the 0.36% heterogeneity on the ecotones came from random factors, 99.74% of which came from spatial autocorrelation. Some 13.10% of heterogeneity on the interdune lowlands came from random factors, 86.90% of which came from spatial heterogeneity. In other words, the degrees of spatial autocorrelation of the seed density on the active sand dunes was week, whereas it was strong on the ectones and interdune lowlands (Jackson and Caldwell 1993; Chen *et al.* 2002).

Table 1: A list of species in the seed banks of the active sand dunes, the ecotones, and the interdune lowland. AH = annual herb, BH = biennial herb, PH = perennial herb, SS = semi-shrub

Species	Family	Life form	Active sand dune	Ecotone	Interdune lowland
Silene jenissensis	Caryophyllaceae	AH			√
Agriophyllum squarrosum	Chenopodiaceae	AH	√	√	√
Chenopodium acuminatum	Chenopodiaceae	AH		√	√
Corispermum candelabrum	Chenopodiaceae	AH	√	√	√
Artemisia wudanica	Compositae	SS	√	√	
Carduus nutans	Compositae	BH			√
Senecio argunensis	Compositae	PH		√	√
Bolboschoenus compacts	Cyperaceae	PH		√	√
Cyperus glomeratus	Cyperaceae	AH			√
Chloris virgata	Gramineae	AH		√	√
Eragrostis pilosa	Gramineae	AH		√	√
Setaria viridis	Gramineae	AH	√	√	√
Glycine soja	Leguminosae	AH			√
Hedysarum fruticosum	Leguminosae	SS		√	√
Sophora flavescens	Leguminosae	PH		√	√
Swainsonia salsula	Leguminosae	SS			√
Thermopsis lanceolata	Leguminosae	PH			√
Polygonum divaricatum	Polygonaceae	PH		√	

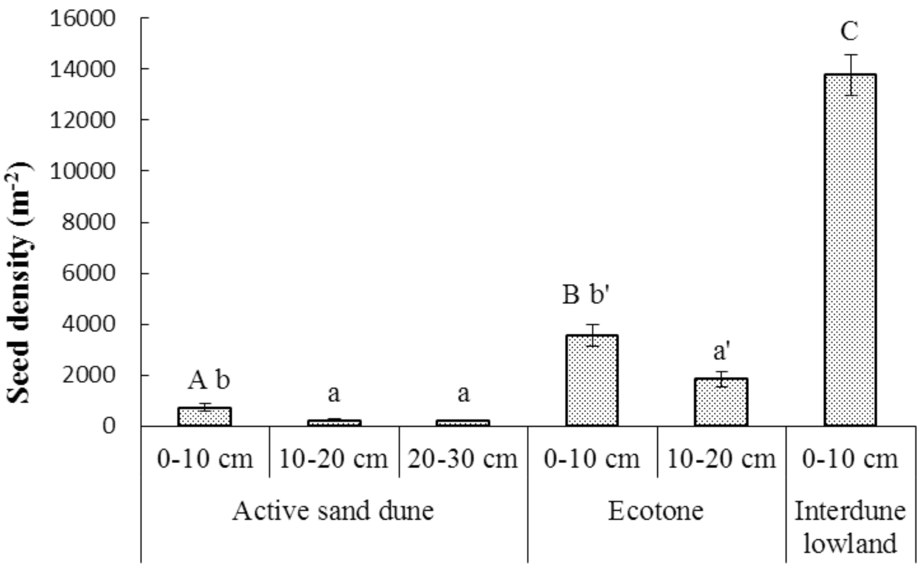

Figure 1: Variation in average seed density (±SE) per m^2 of parts and layers of active sand dune systems.

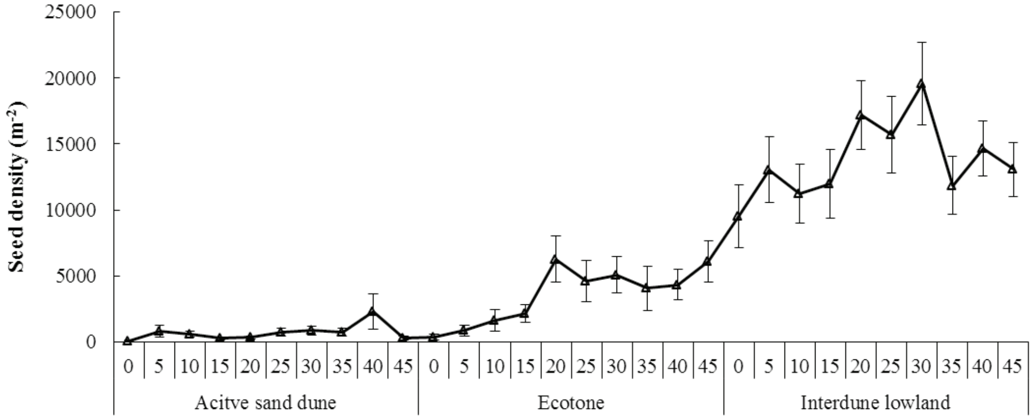

Figure 2: The average seed density along the slope from the top of the active sand dunes to the bottom of the interdune lowland.

The soil seed bank size is the result of the balance between seed input and output (Fenner 1985), and the low seed density could be attributed to a low seed input or production by most pioneer species in the vegetation (Bossuyt and Hermy 2004). Consequently, the lowest seed density on the active sand dunes is mainly because of the low seed input or production when vegetation species are rare (Bossuyt and Hermy 2004; Hölzel and Otte 2004, Bossuyt *et al.* 2007). Moreover, seeds are known to occur clustered in the soil because seed producing plants are generally clustered but not random in the vegetation (Thompson 1986; Bossuyt and Hermy 2004; Bossuyt *et al.* 2007). Therefore, more seeds may have been present on the interdune lowlands than active sand dunes because of the well-developed vegetation.

On the other hand, abiotic factors include wind regime, landform, soil condition, etc. other important factors affecting the temporal and spatial patterns of seed bank (Chambers and MacMahon 1994; Okubo and Levin 1989; Thompson and Grime 1979; Yan *et al.* 2005). In particularly, wind action and sand movement are the most important abiotic factors controlling seed distribution in the active sand dune systems (Yan *et al.* 2005, 2009). Interdune lowlands had abundant reserves of seeds due to the optimal landform and wind breaking effect of dense vegetation (Yan *et al.* 2005, 2009). However, hardly any seeds were present in the active sand dunes and at the side of ecotones under the serious impact of wind erosion and sand movement.

Similarity between the soil seed bank and vegetation, and implications for restoration

The similarity between the soil seed bank and standing vegetation ranged from 13.30% to 29.76%, which was lower (13-30%) compared to what is often found in grassland systems (De Villiers 2003; Kalamees *et al.* 2012). In comparing the seed banks and the standing vegetation we can conclude that poor similarity may be due to the low seed production of the dominant vegetation, generally low seed production, on the active sand dune systems (Ma *et al.* 2012). The species in the soil seed bank of active sand dunes were nearly annual species, and the poor similarity partially related to the lack of perennial species in the seed bank that are common in the standing vegetation (Major and Pyott 1966; Morgan 1998), consistent with Scott and Morgan (2012).

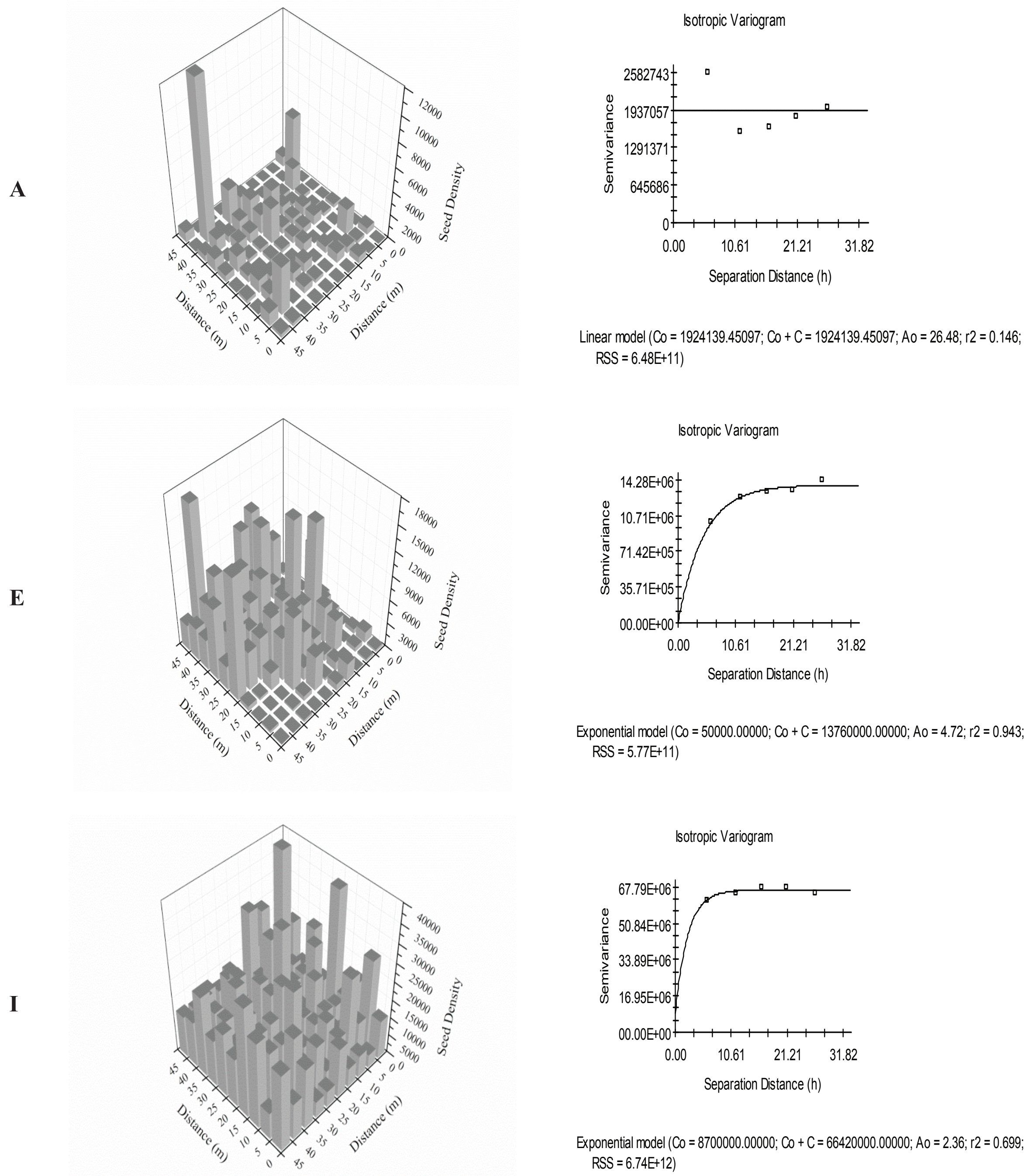

Figure 3: The 3D bars (left) and semivariograms in isotropic (right) of the average seed density on the active sand dune (A), the ecotone (E) and the interdune lowland (I), respectively.

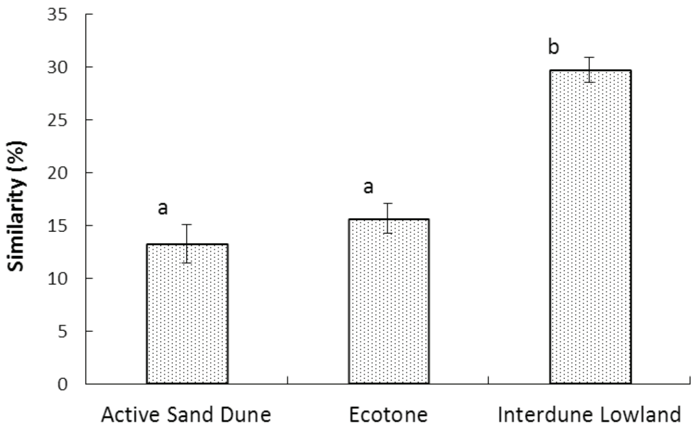

Figure 4: Similarity (±SE) of species composition in the seed bank and standing vegetation in active sand dune, ectone, and interdune lowland.

Poor similarity between the standing vegetation and the soil seed bank may also be caused by species present in the seed bank, owing to persistence (Thompson and Grime 1979) or dispersal (Thompson and Grime 1979; Dolle and Schmidt 2009). The results showed the regeneration potential of soil seed banks of active sand dune systems was limited, and soil seed bank composition was not particularly relevant to explain standing vegetation composition (Yan *et al.* 2005). Consequently, restoration of active sand dunes depends on the dispersal of seeds from nearby plant communities. Dispersal is one of the most important factors in vegetation restoration. When seeds required for restoration are neither in the established vegetation nor in the soil seed bank of the target community, they could be dispersed from neither the local or regional species pool (Bakker 1999). The soil seed on the ecotones and active sand dunes are mainly dispersed from interdune lowlands.

Conclusion

The evidence from our study is that the seed bank tended to reflect former vegetation rather than the vegetation development following restoration. The similarity between soil seed bank and standing vegetation of the ecotones was higher than active sand dune, but lower than interdune lowland. Consequently, vegetation restoration cannot rely on the seed bank on the active sand dunes, and more attention should paid to interdune lowlands protection because it is the main source of seed dispersal and seedlings recruitment in the active sand dune fields.

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Comparison of the methods of extraction of information on wetland in inland river basin of northwest China: a case study in Zhangye city

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Abstract

Taking the Zhangye City in inland river basin of Northwest China as the research area and selecting TM image of Landsat 5 as data source, the wetland information were extracted by using Iterative Self-Organizing Data Analysis Technique (ISODATA), Maximum Likelihood Classification (MLC), Support Vector Machine (SVM), Artificial Neural Network (ANN) and Object Oriented Approach (OOA). Comparison of the extraction results showed that each method is suitable for extracting the wetland information. Some conclusions obtained are: 1) The overall accuracy of OOA was the maximum (75.1%) with perfect continuity. The accuracy of ISODATA was the minimum (56.67%) and many over extraction regions. 2) Although the overall accuracy of MLC, SVM, and ANN was lower (63.26%, 72.56% and 72.21%, respectively) than OOA, they also had reference for extraction. 3) There were some differences in results of shallow water area, marshes and small ponds. The result not only of OOA but also of ANN and SVM had the same phenomenon, which gave imperfect information on patches of small ponds. Near the regions of shallow water area and marshes, some farmlands were wrongly identified as wetland by ISODATA and MLC.

Introduction

Wetlands are areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters (UNESCO 2004). Wetlands constitute an important ecosystem of the land surface, maintaining the logistic and the ecological balance of the land surface with forests, grasslands and farmlands ecosystem - an irreplaceable natural complex (Gong *et al.* 2007). However, the protection of wetland resource was ignored in the long-term process of development and utilization of land, resulting in a reduction of wetland area, loss of biodiversity and increasing pollution, with a negative impact on people's life (Zhang *et al.* 2012).

With the development of science and technology, remote sensing technology has become an advanced way to study wetland environments (Dai 1995) , and a lot of research has been done. For example, Wang *et al*. (2009) used the TM image and DEM data to extract the wetland information of Maqu County by constructing a decision tree model with the accuracy of 82.9%. Li and Jia (2008) distinguished different types of wetlands successfully by putting forward a new method, which combined tasseled cap transformation with decision tree classification method, and made a detection of the two phases. Zhang *et al.* (2011) used SVM and TM image to extract the wetland information in Zhalong, with the accuracy of 88.12%, which was better than that using MLC. Sun *et al.* (2008) extracted the wetland information in the source region of the Yellow River successfully by using OOA and ETM+ data, with smooth polygon boundary and the accuracy of 93.34% .

Since there are several methods, most researchers hold the opinion that there are no universal methods to extract specific wetland information in different regions (Yang *et al.* 2012). But so far, there are only a few studies on the wetland extraction methods in inland river basin of Northwest China (Zhou 2005). In this paper, different methods were compared in order to select an optimal one that could serve as a reference for the extraction of information on wetland in inland river basin.

Study area

The study area is located in Ganzhou and Linze County of northwest Zhangye (Fig.1) in Heihe River Basin (100°6' 10 " to 100°27' 18" E and 39°1' 22 " to 39°20' 14"N). It has abundant water resources and diverse types of wetlands along the river banks, which are the typical desert-oasis wetlands in inland river basin. Because of the impact of reduced rainfall and global climate warming and drying, the ecological environment of the area is very fragile (Liu *et al.* 2008). Furthermore, the dramatic increase in population, urbanization, pollution and destruction of wetlands, the regional ecological environmental degradation and shrinking of the natural wetland area are becoming increasingly serious problems (Chen 2010).

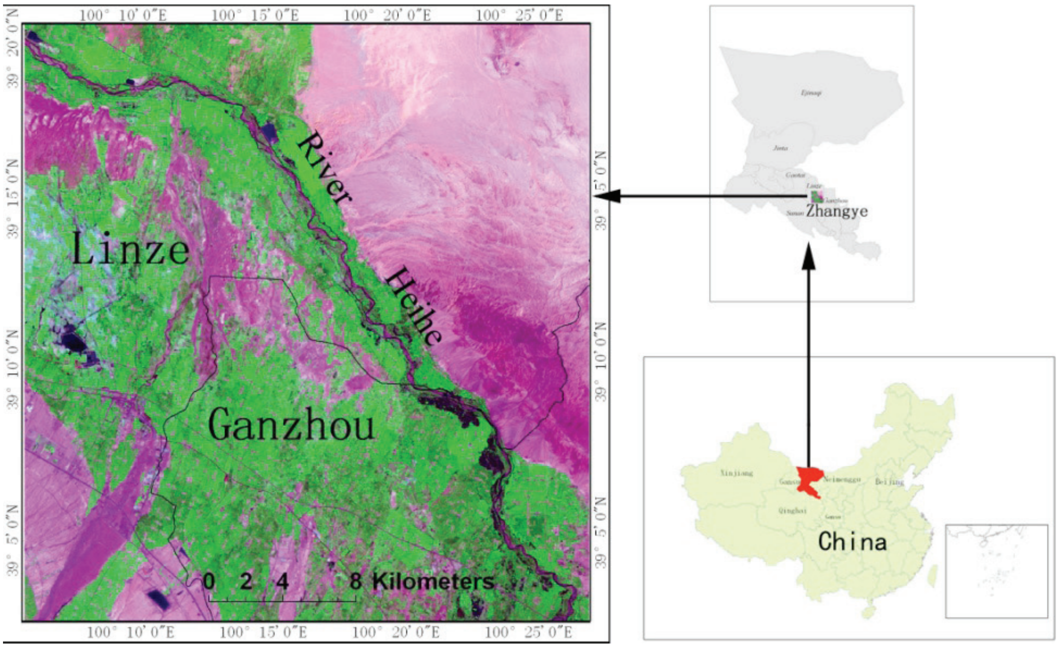

Figure 1: The location map of study area

Data

TM image is medium-resolution remote sensing image (Zhang *et al.* 2003) [13]. It is very useful for wetland monitoring and classification in large area, although its spatial resolution is not high. It has been used in wetland monitoring at home and abroad (Li *et al.* 2007) [14], with the accuracy meeting the requirements of the wetland research. In our study, the TM image of Landsat 5, acquired on 3rd August, 2006 was used.

Methodology

ISODATA

ISODATA is an unsupervised classification algorithm that is widely used (Huang,2002). The essence of this method is an iterative cycle. Cluster centers are randomly placed and pixels are assigned based on the shortest distance to center method. The standard deviation within each cluster and the distance between cluster centers are calculated. Based on them, clusters are split or merged. A second or further iteration is performed with the new cluster centers until the average inter-center distance falls below the user-defined threshold or the maximum number of iteration is reached (Jahne 1991). Distance calculation formula is shown in equation (1).

$$Dis = \sqrt{\left(BV_{ijk} - \mu_{ck}\right)^2 + \left(BV_{ijl} - \mu_{cl}\right)^2} \qquad (1)$$

where BV_{ijk} and BV_{ijl} are TBD pixels. Dis is the distance between TBD pixel and each mean vector. μ_{ck} and μ_{cl} are the mean vectors of the K band and L band of C class.

MLC

MLC is one of the most widely used supervised classification algorithm (Wu and Shao 2002). It assumes that the training data statistics for each class in each band are normally distributed as equation (2) and the discriminant-rule is based on the probability. Using the priori distribution of knowledge and its probability, the probability of a pixel relegating to various classes was calculated. And then the pixel is divided to the maximum probability of the class.

$$p(x \mid wi) = \frac{1}{\sqrt{2\pi} * \sigma i} \exp\left[-\frac{1}{2}\frac{(x-\mu i)^2}{\sigma i^2}\right] \qquad (2)$$

where *wi* is a class, χ is the pixel value, µi is the mean of all estimation values of class, σi^2 is the variance of all estimation values of class. Therefore, a pixel of the remote sensing images will be classified if the mean and variance of the training samples are calculated.

SVM

SVM is an effective method of machine learning, which is built on the basis of statistical learning theory (Cortes and Vapnk 1995). Its general expression (Yao *et al.* 2008) is shown in equation (3).

$$f(x) = sign\left[\sum_{i=1}^{k} a'_i \, y_i K(x_i, x) + b'\right] \qquad (3)$$

where *x (xi, yi)* is a group of classification samples, *k* is the number of samples, *b'* is classification threshold.

ANN

ANN is defined by neurons, topological structure and learning rules. The neuron is similar to the biological neuron of human brain, which is made up of collection, weight, processing unit and output (Hagan et al. 1996). Each input *xi* and weight *wi* were multiplied to obtain *xiwi.* Then it was transferred to the processing unit in the accumulation unit. An offset *b* could also be plused on the whole equation (4).

$$net = \sum_{i=1}^{p} (x_i w_i) + b \qquad (4)$$

The net as the input was taken to activate the transfer function equation (5) that can get y as the output by the conversion algorithm (Jensen *et al.* 1999).

$$y = f(net) = f\left[\sum_{i=1}^{p} (x_i w_i) + b\right] \qquad (5)$$

OOA

The basic principle of OOA is that the characteristics of shape, color, texture, etc. are combined to make up an image object according to the same characteristics of the pixels. And then these image objects are classified in accordance with the characteristics of each object. There are two commonly used methods of OOA, which include the nearest neighbor and membership function. In this paper, the nearest neighbor method was used. The nearest neighbor classification feature space was made up of the relevant characteristics and a certain number of representative objects. Using the nearest neighbor classifier to calculate the distance of TBD objects of each class, the values to the membership degree of each class were assigned in accordance with the size of the distance. Then, the image objects was classified by the membership degree. The mathematical principle is as equation (6).

$$d = \sqrt{\sum f \left[\frac{v_f^{(s)} - v_f^{(o)}}{\sigma_f} \right]^2} \qquad (6)$$

where d is the distance between the sample object and image object, $v_f^{(s)}$ is *eigenvalue* of the sample object to feature f, $v_f^{(o)}$ is *eigenvalue* of image object to feature f, σ_f is the standard deviation of feature f.

OOA is based on image segmentation, of which the main task is to split the image into a certain number of non-overlapping polygons. The multi-resolution segmentation parameters in eCognition8.0 include the scale, shape, compactness, etc. Considering the situation of the study area, the images are segmented for two levels (Level 1 & 2) with the scale parameter selected by 5 and 10 (Table 1). Level 1 is used for the extracting image object and level 2 is used for getting a suitable segmentation for the image object of level 1.

Table1: Image segmentation parameters

Level	**Scale**	**Shape**	**Compactness**
1	5	0.1	0.5
2	10	0.2	0.9

Accuracy examination

In order to check the accuracy of the results obtained through the five methods and select the optimal one, the result of Visual Interpretation was regarded as a reference and the accuracy of extraction results for the other methods was assessed using equation (7).

$$\omega = \frac{A \cap B}{B} * 100\% \qquad (7)$$

where ω is the result of assessment , A represents relatively real wetland area, B means the area of extraction results, and $A \cap B$ expresses the effective extraction area of wetland.

To test the applicability of the above methods, the effective area index was introduced to express the extraction accuracy. The higher value of effective area index, the better the intensity of method's applicability. The expression is as equation (8).

$$\sigma = \frac{A \cap B}{A} * 100\% \qquad (8)$$

where σ is the effective area index, A, B and $A \cap B$ have the same meanings as above.

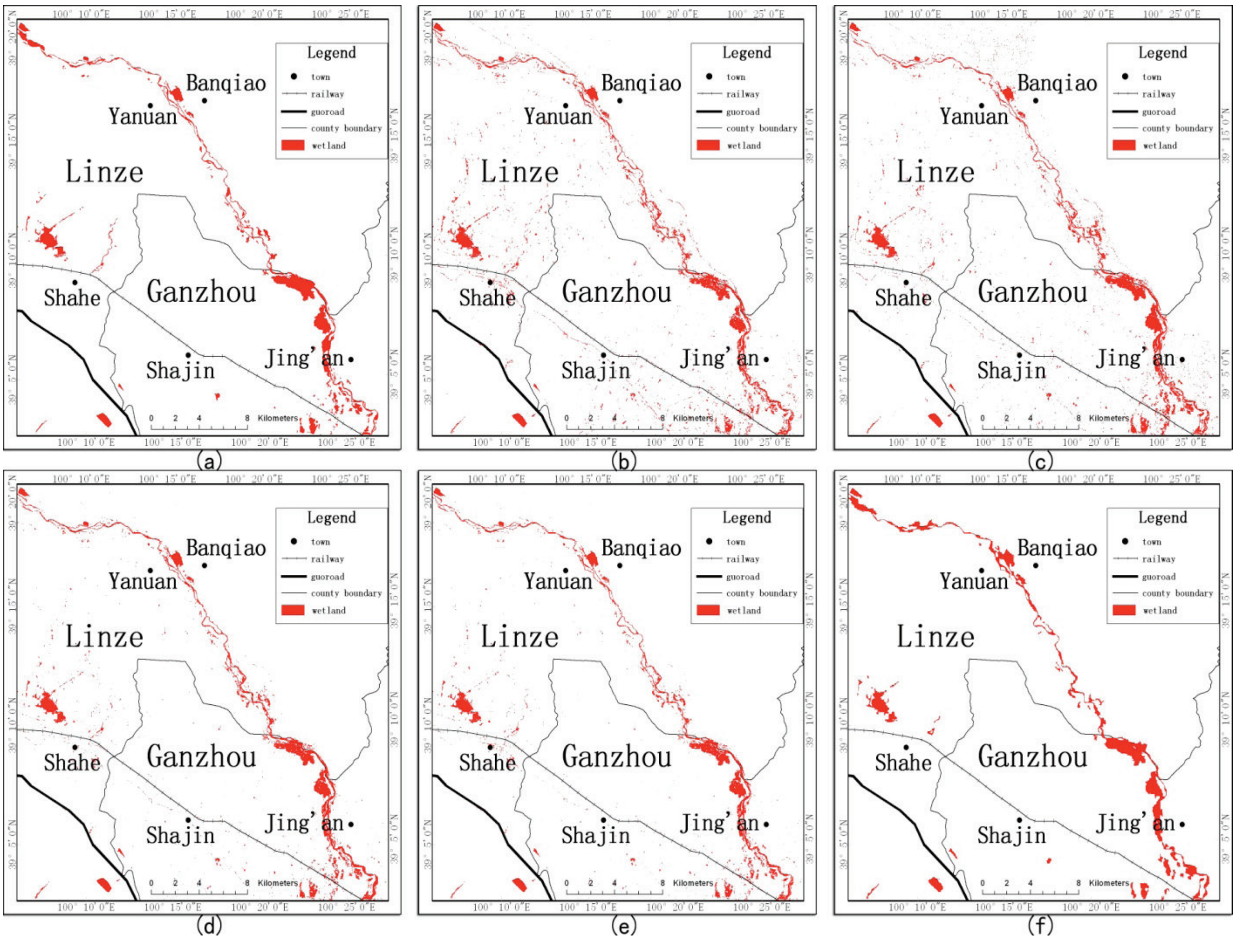

Figure2: Wetland extraction result of different methods; (a) Visual interpretation; (b) ISODATA; (c) MLC; (d) SVM, (e) ANN; and (f) OOA.

Analysis of results

Information extraction

Combined with field trips, the spatial distribution of wetland in study area (Fig.2a) was obtained through the Visual Interpretation based on high-resolution remote sensing images, which were provided by Google earth. Meanwhile, the wetland information was extracted by ISODATA, MLC, SVM, ANN and OOA provided by ENVI4.8 and eCongnition 8.0 separately.

The parameters of ISODATA were set, with the number of initial class of ten, the number of maximum class of twenty, the number of least pixels of one, the maximum standard deviation of one, the minimum class distance of two, the threshold of 2%, and the number of maximum iterations of 99.The result is shown in Figure 2b. In the process of MLC, 200 training samples were selected, with the help of prior knowledge, high-resolution remote sensing images and field survey data. The result is shown in Figure 2c. In the process of SVM and ANN, the same training samples of MLC were used. The main parameters of ANN were set with the activation of logistic, the training threshold contribution of 0.5, learning step rate of 0.2, and training RMS Exit Criteria of 0.1.The results are shown in Figure 2d and Figure 2e separately. The result based on OOA is shown in Figure 2f, with the Image segmentation parameters as shown in Table 1.

The results of each method generally reflected the status of the spatial distribution of wetlands, with the same results in large reservoirs and the deep water areas of rivers, whereas, there were large differences in identifying small ponds and the shallow water areas. As the methods of ISODATA, MLC, SVM and ANN are based on pixels, there is a phenomenon of "salt and pepper" in results. It is avoided in the method of OOA, which is based on image objects, and the extracted boundaries are smooth. But further examination is needed to test the accuracy of the results.

Area analysis

The areas of extraction for all above methods are counted and shown in Figure 3. The area extracted by Visual Interpretation is 22.05 km², largely reflecting the real scale of the wetland in study area. The area of MLC is the largest with the value of 27.57km², followed by OOA. Compared with Visual Interpretation, the areas of ANN and SVM are closer to actual. But the results need to be further verified.

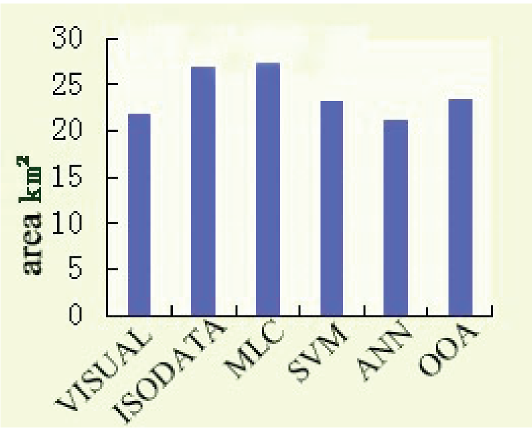

Figure 3: The results of wetland area statistics.

Accuracy examination

According to the method of accuracy examination, the $A \cap B$, ω and σ were calculated and the results are shown in Table2.

Table 2: The results of accuracy examination

Methods	ISODATA	MLC	SVM	ANN	OOA
$A \cap B$ (km²)	15.29	17.44	16.98	15.46	17.67
ω (%)	56.67	63.26	72.56	72.21	75.10
σ (%)	69.34	79.09	77.00	70.11	80.13

It shows that OOA has higher accuracy than other methods, followed by SVM and ANN. Obviously, the problem of over estimation existed in the methods of ISODATA and MLC, which led to the relatively low precision. The reason maybe that remote sensing images sometimes present simultaneously "same object with different spectra" and "different objects with same spectrum" characteristics. The ISODATA only relies on the spectral feature, thus it cannot extract the entire information of wetland. The wetlands in study area are mainly reservoirs and river wetland, and their distribution probably is not normal (Zhang *et al.* 2011a), which may result in the low precision of MLC. Effective area index of OOA is the highest, which means its applicability is better than that of other methods. Although the effective area index of SVM and MLC are lower than that of OOA, they are still important for the information extraction of wetlands.

Conclusion

Results show that each of the studied method can be used to extract wetland information. However, the results are quite different in shallow water area, marshes and small ponds. While the patches based on OOA were incomplete in the regions of small ponds, some farmlands were wrongly extracted as wetland near the regions of shallow water area and marshes by using methods of ISODATA and MLC. Taking into account the factors of the spectrum, shape, color and other characteristics of the object, the result based on OOA, which overcomes the "salt and pepper" phenomenon caused by landscape fuzzy boundaries and larger internal heterogeneity, is the best one, with fine continuity and the highest accuracy of 75.10%. The ISODATA gave the lowest accuracy and had much over extraction. In spite of low accuracy of MLC, it gave high effective area index, which is important reference for wetland extraction. The accuracy of SVM and ANNwas better than that of MLC, but with many fragments in results.

As many wetlands cover an area less than 900m², which equals a pixel of TM image, and the width of some rivers in study area is less than 30m, spatial resolution of images is an important factor limiting the extraction accuracy. Therefore, using higher resolution and multi-source remote sensing data will be the trend in future wetland monitoring. In addition, a wealth of prior knowledge is needed in samples selection, parameters determination, *eigenspace* building and other steps of extraction process, especially in the method of OOA. Therefore, subjective cognition is very important in the extraction of information. Reducing the degree of human intervention or developing an intelligent information processing method should be the priority for further research.

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Can no-till cropping alleviate water and heat stress?

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Abstract

No-till cropping systems, which include zero tillage with standing stubble and continuous cropping, are known to reduce soil erosion, improve soil quality and increase soil C sequestration compared to conventional practices. They are also generally associated with greater amounts of soil water and higher water use efficiencies, often resulting in a yield advantage. Recent studies found that no-till can buffer the extremes in soil temperatures reducing the damage caused by frost or heat stress. The warming trend associated with climate change could cause more frequent and severer water and heat stress in arid and semi-arid areas. We hypothesized that no-till cropping systems may provide an effective practice to reduce water and heat stress to cope with the climate change. A mini-rhizotron field study was conducted in the semiarid Brown soil zone of southern Saskatchewan with heavy surface residue and no residue treatments for spring wheat (*Triticum aestivum L.*), dry pea (*Pisum sativum*) and canola (*Brassica napus*). Results showed that surface residue improved near soil surface moisture in the early growing season and reduced near-surface soil temperature over the entire season, thus reducing water and heat stress. The improved near-surface soil environment increased total root length at the 0-50 cm soil depth for wheat and canola, but not for dry pea. Under the heavy residue treatment all the crops were taller than those under the no residue treatment. Grain and straw yield were increased for all crops, but were only significant for straw in canola. Although further studies are needed, this study supported the hypothesis that a no-till cropping system could improve plant performance in this area under the current and future climates.

Introduction

No-till cropping, *herein* referred to as a combination of no-till with standing stubble and continuous cropping (NT), has been increasing on the Canadian Prairies in recent years. It is well recognized that NT practice has environmental benefits, such as reducing soil erosion (Cutforth and McConkey 1997), improving water quality (Yates *et al.* 2006), increasing soil biological activity (Biederbeck *et al.* 1997), reducing CO_2 emission (Curtin *et al.* 2000) and increasing soil C sequestration (Campbell *et al.* 2001). Agricultural production can be improved by practicing NT (Lafond *et al.* 2006) through increasing soil moisture (Lafond *et al.* 1992), improving soil quality (Arshad *et al.* 1999; Campbell *et al.* 1989) and soil fertility (Janzen *et al.* 1998). The economic return for producers can also be increased (Zentner *et al.* 2002) by NT through improving energy use efficiency (Zentner *et al.* 2004), saving farm machinery-life and reducing labor amounts and costs, while maintaining or improving crop yields.

Another possible impact of NT on agricultural ecosystems is that it could modify the dynamics of near-surface soil temperatures compared to a conventional tillage system (CT). The near-surface soil temperature under NT can be lower than that under CT because the surface residue can intercept and reflect the incoming solar radiation (Baver *et al.* 1972) and reduce the heat flux toward the soil profile (Azzoz *et al.* 1997). Surface residue and the higher soil moisture under NT can also buffer the extremes in daily soil temperatures, i.e. decreasing the maximum soil temperature and increasing the minimum soil temperature (Lal and Shukla 2004).

In the Canadian prairies the average near-surface soil temperature under NT is often lower than that under CT in the early growing season (Carter and Rennie 1985; Malhi and O'Sullivan 1990; Cutforth and McConkey 1997). Although Carefoot *et al.* (1990) found the difference is diminished as the crop canopy develops, some authors observed the relatively cool soil under NT in the mid-season (Gauer *et al.* 1982), or even throughout the whole growing season (Merrill *et al.* 1996; Wang *et al.* 2007).

The cooling effect of NT could reduce early growth (Aston and Fischer 1986; Hay 1977; Hay and Wilson 1982). A reduction of yield under NT was reported for warm season crops, such as corn (*Zea mays*) (Wall and Stobbe 1984), but some other studies found comparable or increased yields in corn under NT compared to CT (Al-Darby and Lowery 1987). Yield reduction in wheat under NT was observed in Australia (Aston 1987; Fischer 1985) and the U.K. (Davies and Cannell 1975), but in the Canadian Prairies the cool soil temperature generally had little impact on the growth and yield in wheat (Carter and Rennie 1985; Carefoot *et al.* 1990) and other cool season crops, such as canola *and dry pea* (Arshad *et al.* 1995; Bullied *et al.* 2003; Harker *et al.* 2012). Field observations found the kill temperature could be as low as −8°C for spring wheat (Macdowall 1973; He *et al.* 2012), and −6°C for canola (Johnson *et al.* 1995) and dry pea (Cutforth *et al.* 2007).

The decreased maximum and increased minimum near-surface soil temperature under NT may reduce the damage caused by extreme soil temperatures, such as frost and heat stress. Gauer *et al.* (1982) reported that winter wheat was killed under CT by the seedbed temperature of -17°C, while winterkill did not occur under NT because the seedbed temperature was only -8°C. Arshad *et al.* (1995) observed that canola population under CT was significantly lower than under NT which was attributable to greater damage from a frost of -8°C on CT plots, while due to the insulating effect of residue present on or near the soil surface, plants under NT had relatively little damage.

Regarding heat stress, Merrill *et al.* (1996) indicated that due to the superior moisture and cooler soil temperature plants are less subject to thermal and radiative stress under NT compared to under CT resulting in increased root and tiller growth in wheat. In a long-term tillage study conducted on a Thin Black Chernozemic clay loam in central Alberta, Wang *et al.* (2007) observed no-till wheat had increased above-ground biomass (33–160%) and grain yield (18–147%) in three heat-stressed years. High soil temperature and heat shock (>32 ^{o}C, Wardlaw *et al.* 2002) occurred at the depth of 5cm from anthesis to grain fill stage in CT plots. Under NT, however, soil temperature was always lower than CT during diurnal peak hours and no heat shock was observed. Wang *et al.* (2007) concluded that the increased biomass and yield under NT could be attributed to increased soil moisture and reduced heat stress. Based on the analyses on a 25 years' long-term experiment conducted on a Swinton silt loam in the semiarid Brown soil zone of the Canadian prairies, Wang *et al.* (2008) found above-ground biomass of wheat using NT practices averaged about 250 kg ha^{-1} more than under CT, which was associated with the slightly higher pre-seeding near-surface soil moisture and reduced root heat stress.

Root heat stress could cause lower root growth (Nielsen 1974), reduction of photosynthate partitioning to shoots (Li *et al.* 1994) and *senescence acceleration* (Martin and Thimann 1972). Root heat stress alone or whole plant heat stress could reduce significantly more yield than shoot heat stress alone (Guedira and Paulsen 2002; Kuroyanagi and Paulsen 1988). The warming trend of climate change could cause more frequent and more severe heat stress in the Canadian Prairies (Abrol and Ingtan 1996; Hengeveld *et al.* 2005; Parry 1990). If NT practices can reduce root heat stress, it could be an effective strategy to cope with the future climate and increase production.

The objective of this study was to use a mini-rhizotron technique to determine if mimicked NT residue conditions can benefit root growth through improved soil moisture and reduced heat stress and its association with growth and yield in wheat, canola and dry pea in the dryland of southern Saskatchewan. Results of this study may provide us hard evidence on how NT affects plant growth and help us understand the physiological basis of plant performance under NT.

Materials and methods

A field study was conducted in 2009 on a Swinton silt loam (Orthic Brown Chernozem) at the Semiarid Prairie Agricultural Research Centre near Swift Current, Saskatchewan (50^{o}16'N, 107^{o}44'W, 825 m with mean annual temperature of 3.6ºC and average annual precipitation of 364 mm). A factorial, randomized complete block design was used in this study. The first factor was species and the second factor was residue treatments. Canada Prairie Spring wheat (cv. AC Vista), Canola (cv. 5440LL) and dry pea (cv. Meadow) were seeded in a wheat stubble field with two residue treatments: no residue and heavy residue. The no residue treatment was implemented by removing all stubble and surface residue off the field except uncollectible chaff. The residue collected from each no residue plot was then evenly placed on each heavy residue plot. Thus, the heavy residue treatment had about two times of the original surface residue (9226.6±882 kg ha^{-1}). The plot size was 2 m × 6 m, seeded on May 11, 2009 with a hoe type drill with a dual chute seeding system on a 25 cm row spacing. Seed and phosphate fertilizer were placed to one side of the boot while urea fertilizer was placed to the other side. Canola was seeded at a rate of 11.8 kg ha^{-1} approximately 1.5 to 2 cm deep, wheat was seeded at a rate of 106 kg ha^{-1} approximately 2.5 cm deep, and the field pea was seeded at a rate of 160 kg ha^{-1} approximately 5 cm deep. Fertilizer P was applied at a rate of 43 kg ha^{-1} on all plots and urea was applied at 124 kg ha^{-1} for wheat and 135 kg ha^{-1} for the canola. The canola plots were sprayed with 501 g ha^{-1} of glufosinate, the dry peas were sprayed with imazamox and imazethapyr at a 1:1 ratio of 15.1 g ha^{-1}, and the wheat was sprayed with tralkoxydim at 197.6 g ha^{-1}, bromoxynil at 222.3 g ha^{-1} and MCPA at 222.3 g ha^{-1}. The entire trial was sprayed with cabaryl for insect control at a rate of 1896 g ha^{-1}. Weather data were collected from a weather station located about 300 m from the plot area.

Soil temperature and moisture measurements

Right after seeding Campbell Scientific 107-B temperature and CS-616 TDR moisture sensors were placed into two reps of the study. The thermistors were inserted at 10 cm soil depth and the TDR sensors were inserted to monitor the 0-10 cm depth to measure soil surface temperature and moisture. A CR-10X datalogger was programmed to read the sensors every minute the data collected was averaged every 15 minutes for final storage.

Root growth measurements

Minirhizotron tubes 90 cm in length were placed in the plots at a 45 degree angle to monitor root growth. The tubes are made of Cellulose Acetate Butyrate, and are 5 cm inside diameter. An alignment frame capable of achieving angles of 30, 45, 60, 75 and 90 degrees was set at 45 degrees and placed in the field at the point where the tubes were to be inserted into the plot. We placed a soil coring probe with a 5.7 cm outside diameter attached to a slide hammer into the alignment frame and removed a soil core to a vertical depth near 55 cm on a 45 degree angle (Fig. 1). A 45 degree angle was chosen so the roots from across two rows of the plants were able to be monitored without preferentially growing down the surface of the tube. Root videos were collected about once a week since emergence until physiological maturity using a Sony camera with a Carl Zeiss lens connected to a Hawkeye borescope. The videos were then parsed into still images using a program called "Virtualdub" (http://virtualdub.sourceforge.net/). Images were analyzed using RootFly (http://www.ces.clemson.edu/~stb/rootfly/). Files were renamed using a program called Métamorphose2 (http://file-folder-ren.sourceforge.net/) to the WinRHIZOTRON standard so they could be imported into RootFly for analysis.

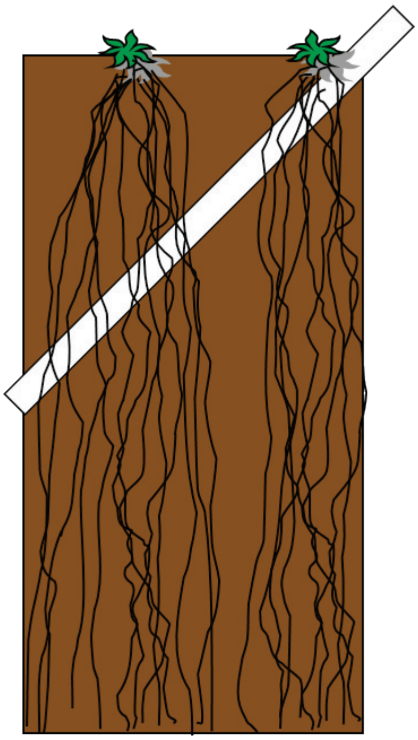

Figure 1: Cross section of minirhizotron tube inserted into the ground.

Yield and biomass measurements

At full maturity the central two rows of the plants in each plot were cut at ground level using pruning shears. Air dried samples were threshed using a Wintersteiger plot combine to separate the grain from the straw (including chaff). Grain weight and total biomass were determined on a per hectare basis. A subsample of grain and straw was used for laboratory analysis of N and P.

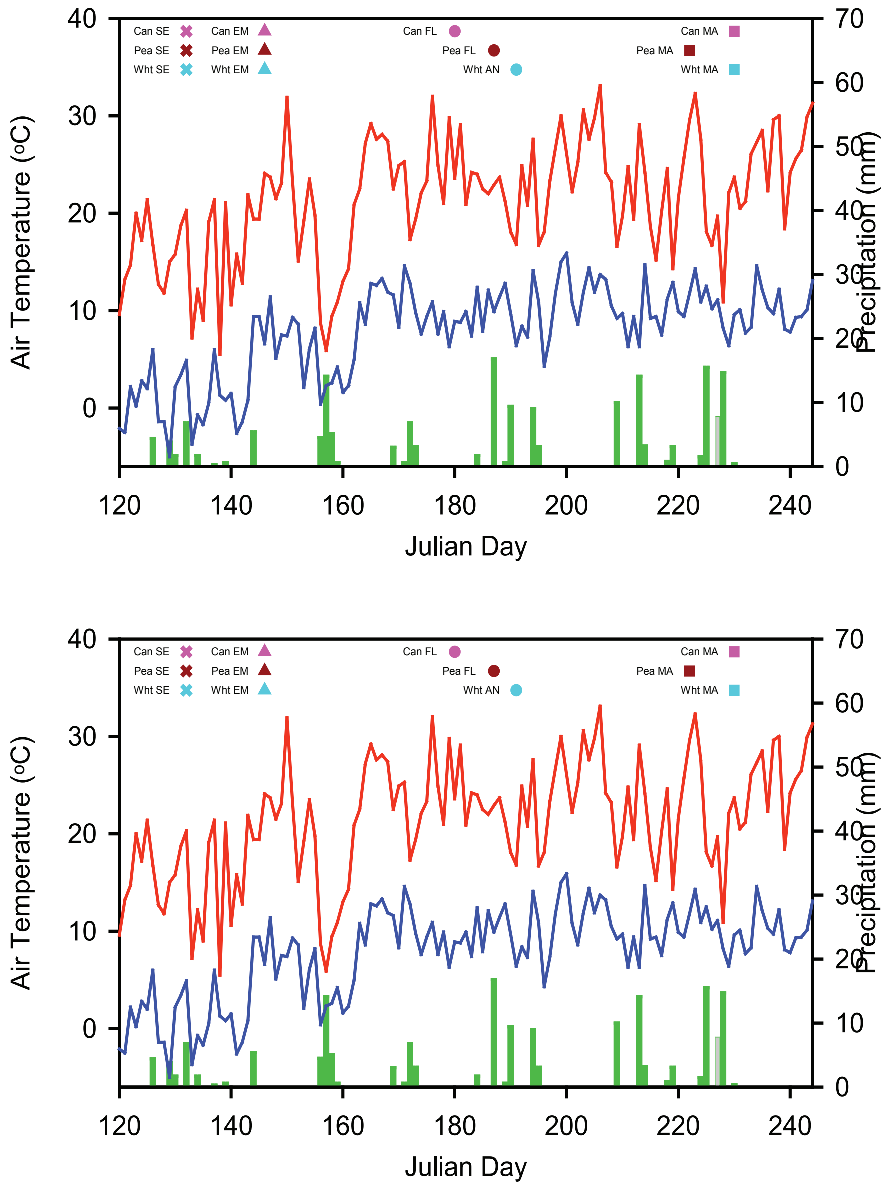

Figure 2: Weather condition and phenology of wheat, canola and dry pea in 2009 where the red line is maximum temperature, blue line is minimum temperature and vertical bars are precipitation. Phenology is described as SE for seeding, EM for emergence, FL for flowering and MA for mature. Crops are Can for Canola, Pea for Dry Peas and Wht for wheat.

Statistical analysis

All dependent variables were analyzed with the Mixed model (SAS Institute, Inc. 1999) using the REML option for each species. Residue treatment, species and their interactions were treated as fixed effect and the rep as a random effect (Littell *et al.* 1998). Root sampling time was treated as repeated measures using the *compound symmetry* covariance structure. Means comparisons were done by Fisher's protected least significant differences (LSD) based on Student's t distribution. "Significance" in the text refers to $P < 0.05$, unless specifically stated.

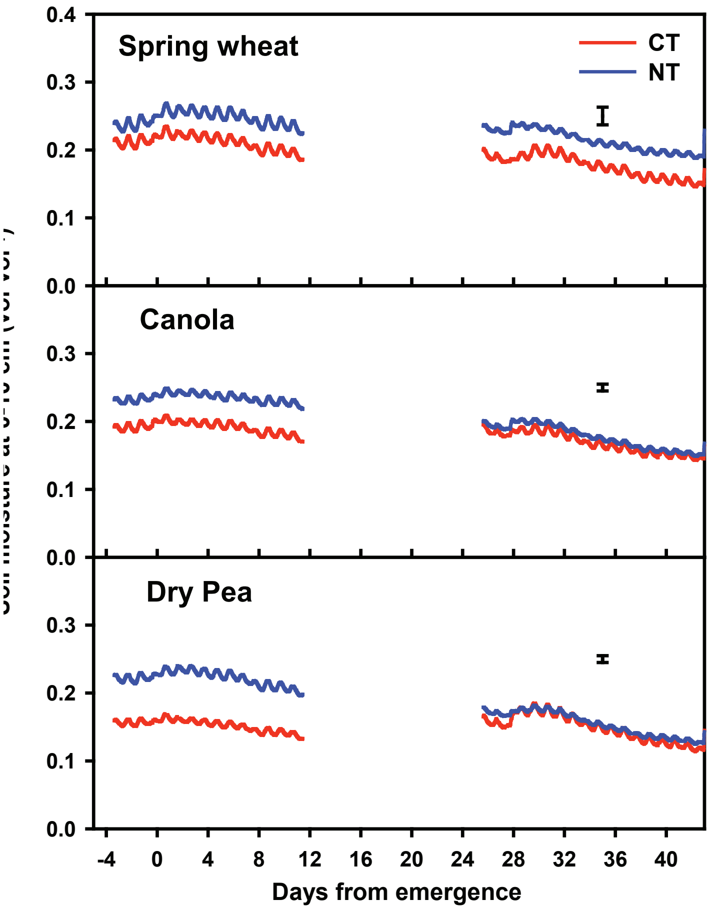

Figure 3: Soil moilsture at 0-10 cm. Vertical bars indicate LSD (0.05).

Results and discussion

Weather conditions

The weather condition in the growing season of 2009 was generally normal (Fig. 2). A total of 176 mm of precipitation occurred during the growing season (May 1st to August 31st) of 2009, which is slightly above the average of 170 mm (1800 to 2012). There were four instances where the maximum air temperature reached 30 °C or above (June 25, July 18, 22, and August 11), which could have severe heat damage on the plants (Friend 1965; Owen, 1971; Saini and Aspinall 1982).

Near-surface soil moisture

The heavy residue treatment had significantly higher soil moisture at 0-10 cm for all three crops than the no residue treatment from emergence (Fig. 3). Because of a power failure no data was recorded for either soil moisture or temperature during 11-25 days from emergence. From 26 days after emergence the difference in soil moisture at 0-10 cm between the two treatments was small for canola (five leaf stage) and dry pea (six leaf stage), but the heavy residue treatment continued to have higher soil moisture than the no residue treatment for wheat (tillering stage) until 43 days after emergence (heading stage) when a heavy rain (17 mm) occurred (data not shown after that).

Near-surface soil temperature

The heavy residue treatment had lower near-surface soil temperature than the no residue treatment in most of the peak hours since emergence for wheat (Fig. 4) and the difference maintained until maturity (94 days after emergence) and the highest difference was 3°C. For dry pea, the heavy residue treatment consistently had higher soil temperature than the no residue treatment and the difference was higher than other two crops with the highest difference of 7.2°C. Unlike wheat and dry pea, the difference in soil temperature between the two treatments in canola was not significant until 26 days after emergence (five leaf stage) when the heavy residue treatment had lower soil temperature than the no residue treatment in most of the peak hours until maturity with the highest difference of 3.4°C.

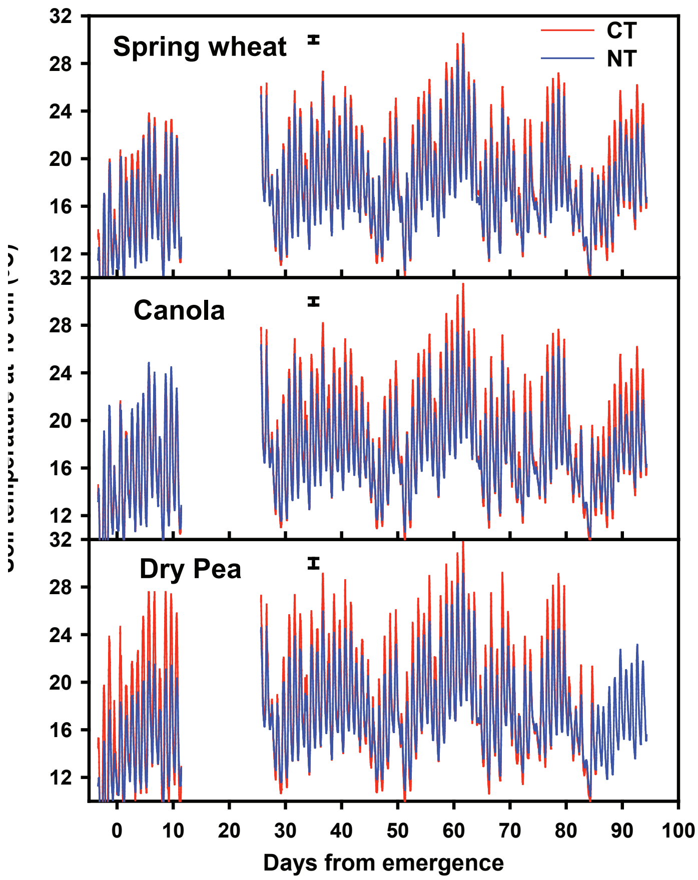

Figure 4: Soil temperature at 10 cm. Vertical bars indicate LSD (0.05).

Root growth

The heavy residue treatment had significantly higher root length density in the top depth (0-10 cm) than the no residue treatment in most of the observation times in wheat (Fig. 5). The difference increased with time until a few days before anthesis. Then, it reduced. At the depth of 10-15 cm, the heavy residue treatment continually had higher root length density than the no residue treatment over the observation time although not always significant. The treatment difference was not significant for the depths deeper than 15 cm except that the heavy residue treatment had higher root length density than the no residue treatment most of the time at 40-45 cm. Overall, the heavy residue treatment had greater total root length at 0-50 cm than the no residue treatment from 32-86 days after emergence (five leaf to soft dough stage) while only significantly for 28-41 days after emergence (flag leaf visible to head emergence).

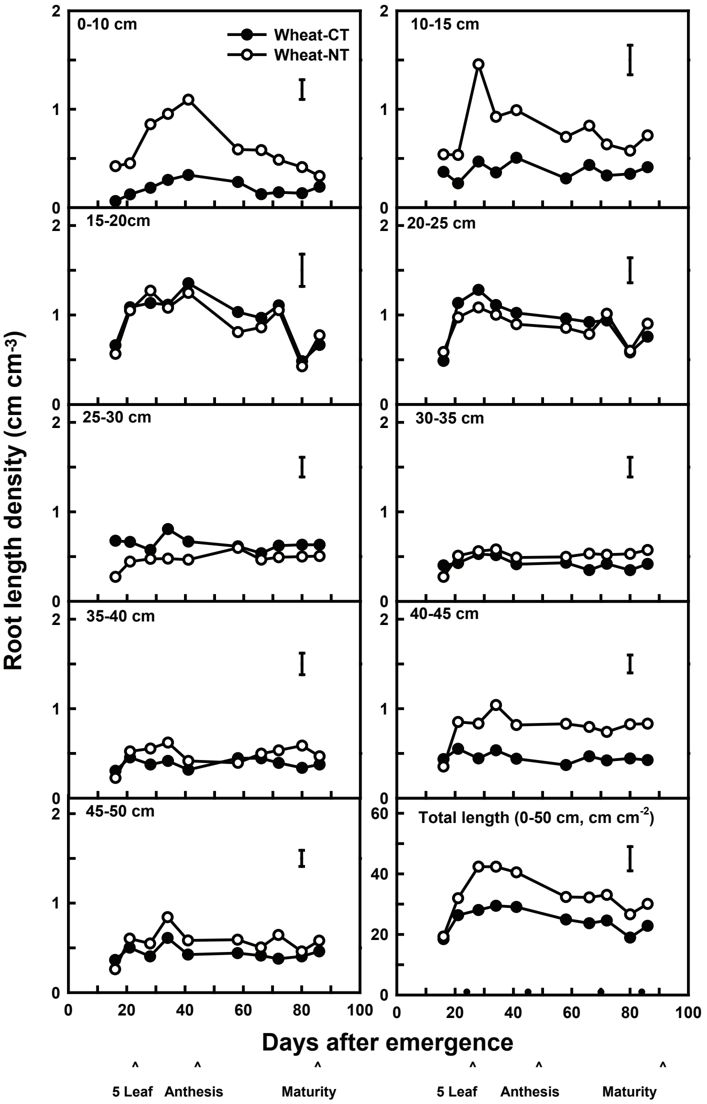

Figure 5: Root length density at different layers and total root length at 0-50 cm of wheat. Vertical bars indicate LSD (0.05).

For canola, the root length did not differ between the two treatments at the 0-10 cm depth (Fig. 6). In the 10 to 20 cm depth, the heavy residue treatment had significantly higher root length density than the no residue treatment from five leaf stage to maturity. In the 20 to 40 cm depth, the heavy residue treatment continually tended to have higher root length density than the no residue treatment while not significantly most of the time. In the 40 to 50 cm depth, the reverse situation existed, but not statistically significant mostly. From nine leaf stage, the total root length at the 0-50 cm depth of the heavy residue treatment was significantly greater than the no residue

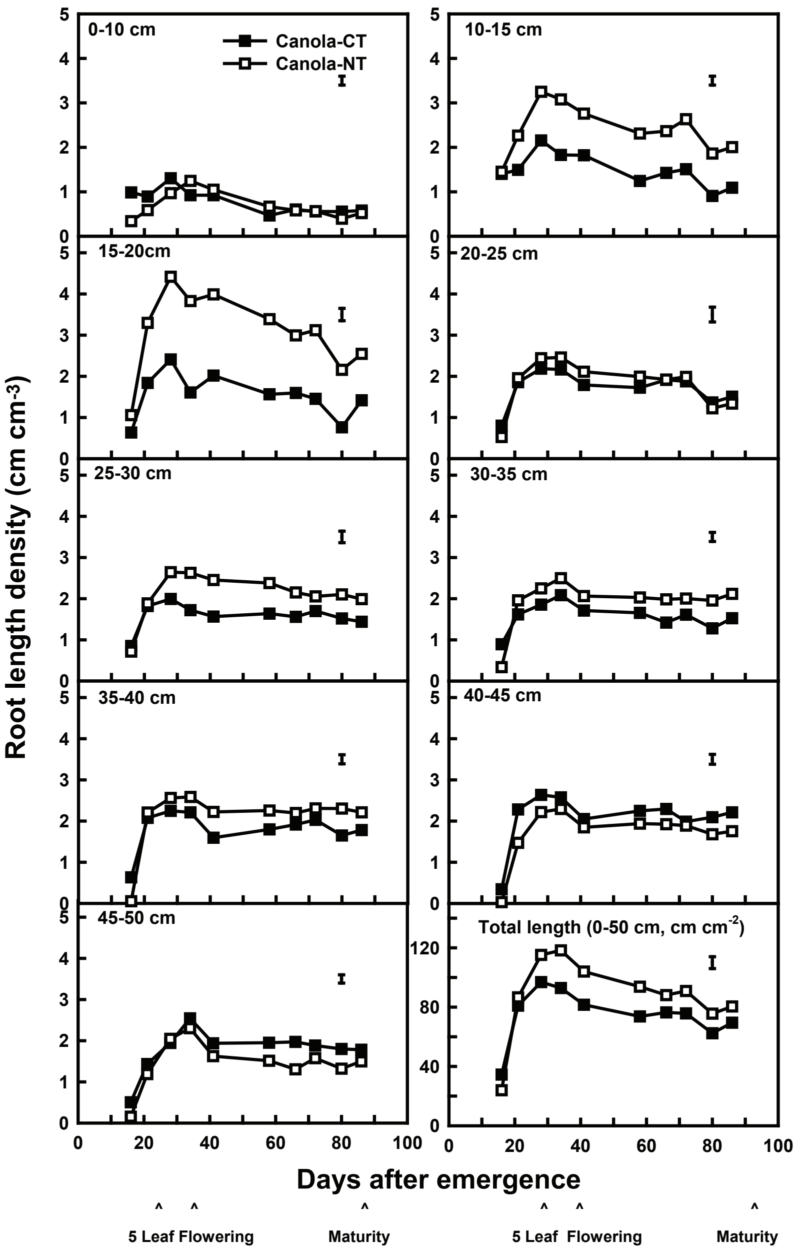

Figure 6: Root length density at different layers and total root length at 0-50 cm of canola. Vertical bars indicate LSD (0.05).

treatment until end of flowing stage and continuously greater with no significance. It is important to note that canola had about three times the total root length at the 0-50 cm depth as spring wheat.

The root growth of dry pea (Fig.7) showed high variability. Hence the treatment difference was generally non-significant.

Wheat and canola had similar root diameters which averaged 0.16 and 0.15 mm, respectively, over the soil profile and the whole growing season. Dry pea had a relatively larger root diameter which

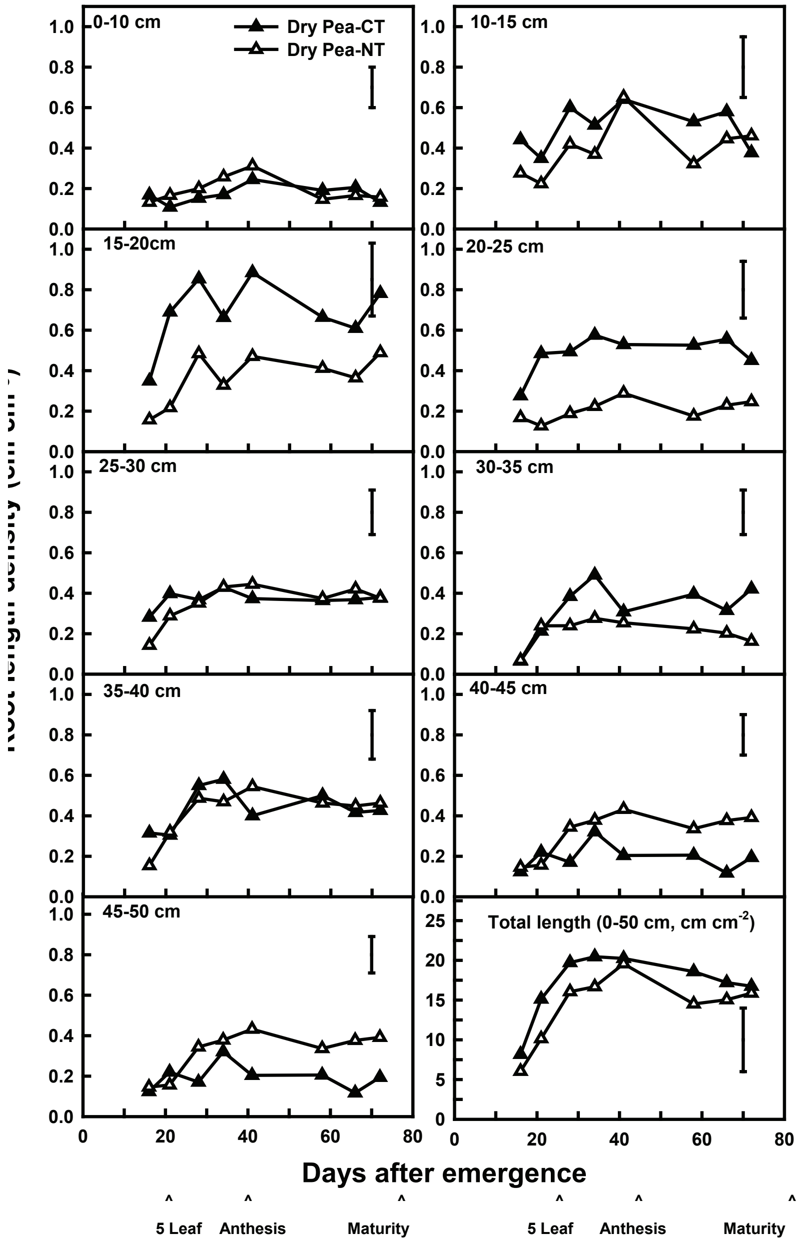

Figure 7: Root length density at different layers and total root length at 0-50 cm of dry pea. Vertical bars indicate LSD (0.05).

averaged 0.24 mm. For either crop, no treatment difference in root diameter was observed (data not shown).which was consistent with reports by Muňoz-Romero *et al.* (2010) and Qin *et al.* (2004)

Yield and straw production

Under the heavy residue treatment all the crops were taller than those under the no residue treatment (Fig. 8). Increases of height by surface residue treatment were 7 cm for wheat (p=0.01), 7.5 cm for dry pea (p=0.01), and 5 cm for canola (p=0.06). The heavy residue treatment produced higher yield than the no residue treatment with 34% for canola, 8% for wheat and dry pea, but none of them was statistically significant. Similarly, heavy residue increased straw production by 52% for canola, 7% for wheat and 20% for dry pea, but it was only significant for canola.

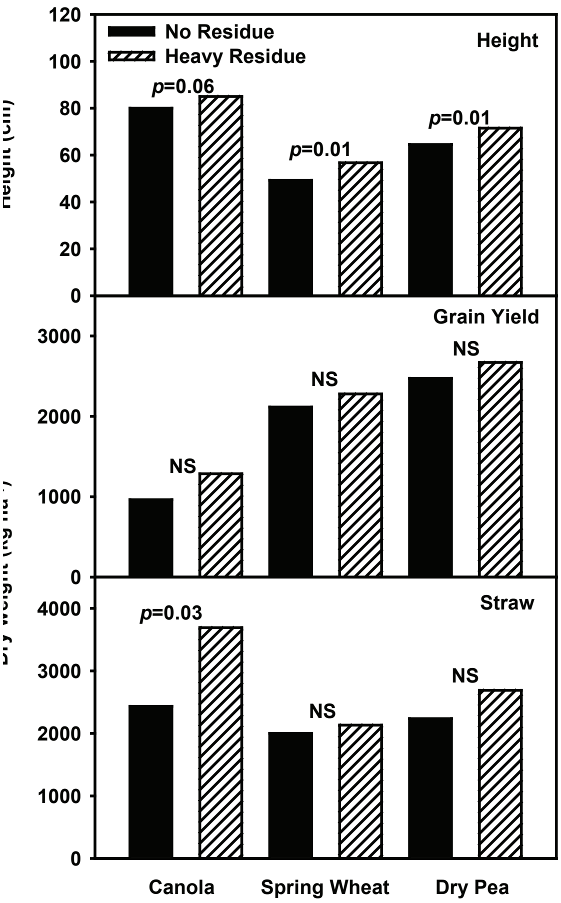

Figure 8: Plant height, grain yield and straw weight. NS: not significant at p = 0.05.

Conclusion

The results from this mini-rhizotron study were consistent with previous studies, showing that surface residue and NT practice can improve near soil surface moisture in the early growing season and reduce near-surface soil temperature over the entire growing season. The improved microclimate conditions near soil surface by retaining surface residue may serve as base in which the benefits of NT practices on promoting root growth, increasing above-ground biomass accumulation and enhancing crop yield can be further explored. Our study showed that heavy surface residue increased total root length at the 0-50 cm depth for wheat and canola, but not for dry pea. Some yield advantages were also realized with heavy surface residue. This study clearly showed that no-till cropping systems improved plant performance through enhancing soil surface microclimate conditions. Further studies are required to explore physiological and environmental benefits of the farming practice.

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Intercropping in castor (*Ricinus communis*) in drylands

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Abstract

A field experiment was conducted to assess the productivity of castor in various plant geometries and to see the feasibility of growing various intercrops in castor under dryland conditions of . Fourteen treatments, consisting of sole crop of castor at 75 cm and 90 cm and in paired rows at 60:90 cm and 60:120 cm, intercropping of 1 row of green gram, moth bean, cluster bean, cowpea and pearl millet in the paired castor row system of 60:90 cm and intercropping of 2 rows of green gram, moth bean, cluster bean, cowpea and pearl millet in paired castor row system of 60:120 cm, were tested in randomized block design with 3 replications. Intercropping of 2 rows of green gram in 60:120 cm paired castor row system gave significantly higher castor equivalent yield (1.35 tonnes/ha), net returns (Rs 9674/ha), benefit: cost ratio (1.63), monetary advantage index (2345) and income equivalent ratio (1.71). Also, intercropping of 1 row of green gram in 60:90 cm castor paired row system was found to be more productive and remunerative than moth bean, cluster bean, cowpea and pearl millet intercropping systems. Intercropping of green gram in paired row planting system of castor either in 1 or 2 rows was found superior than other intercrops in terms of biological parameters like land equivalent ratio, area time equivalent ratio and relative crowding co-efficient.

Introduction

Castor (*Ricinus communis* L.) is most important non-edible oilseed crop of India because of very diversified uses of its oil and high export demand. Unfortunately, castor is raised in India under limited resource conditions and poor yields. Plant geometry plays an important role in increasing the yield of a crop and for castor this needs optimization. Castor is a long duration widely spaced crop with comparatively thin plant population as compared to other field crops and has lot of vacant space in early months of cropping. Thus the crop provides ample scope for growing intercrop in order to increase production per unit area. Intercropping provides substantial yield advantage over sole crop owing to temporal and spatial complementarity and minimizing inter-or intra-specific competition (Chatterjee and Mandal 1992). There is tremendous scope for intercropping short duration crops particularly legumes to utilize the wider inter row space in castor crop. Therefore, five intercrops were tested in the rows of castor with the normal and paired row pattern of planting.

Materials and methods

The field experiment was conducted during *kharif* season in the years 2006 to2009 to assess the productivity of castor in various plant geometries and to see the feasibility of growing various intercrops with castor under dryland conditions. The study was conducted at Dryland Agriculture Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, north India located in semi-arid climate. The soil of the experimental site was sandy loam, low in available nitrogen (203 kg/ha), medium in available phosphorus (16.4 kg/ha), high in available potash (387 kg/ha) content and slightly alkaline in reaction (pH 8.0).

Fourteen treatments consisting of sole crop of castor at 75 cm and 90 cm, castor paired at 60:90 cm and 60:120 cm, intercropping of 1 row of green gram, moth bean, cluster bean, cowpea and pearl millet in castor paired row system of 60:90 cm and intercropping of 2 rows of these intercrops in castor paired row system of 60:120 cm were tested in randomized block design with 3 replications. A basal dose of 40 kg N + 20 kg P_2O_5/ha was applied in the form of urea and diammonium phosphate before sowing of the crops. All the crops were sown on 15 July 2006, 24 June 2007, 26 June 2008 and 17 July 2009 in 9.0 m x 3.6 m plots. Two seeds of castor were dibbled at 60 cm spacing in the rows as per crop geometry treatments, whereas all the intercrops were sown continuously in the rows. In 1 row intercropping system, seed rate for legumes and pearl millet was 5 kg/ha and 1.25 kg/ha while in 2 rows intercropping system, it was 8 kg/ha and 2 kg/ha, respectively. In all the intercrops plant to plant distance of 15 cm was maintained by thinning at 20 days after sowing. Likewise, one plant of castor was maintained at 60 cm distance in all the rows by pulling out the additional plant, if both seeds germinated at one spot. The cultivars 'DCH 7' of castor, 'Muskan' of green gram, 'RMO 40' of moth bean, 'HG 563' of cluster bean, 'HC 98-46' of cowpea and 'HHB 67' of pearl millet were used. Picking of castor was done 3 times at 120, 150 and 180 days after sowing. Intercrops, i.e. green gram, moth bean, cluster bean, cowpea and pearl millet were harvested at 88, 74, 112, 81 and 72 days after sowing.

The total rainfall received during the crop growth season was 131, 249, 382 and 243 mm during 2006, 2007, 2008 and 2009, respectively. The number of dry spells of more than 10 days experienced by the crop was 2, 4, 4 and 3 during 2006, 2007, 2008 and 2009 seasons, respectively.

The pooled grain yields of all the crops in the sole crop as well as in intercropping systems were subjected to statistical analysis only after conversion into the castor equivalent yield taking into consideration the average market prices of 100 kg grain (castor Rs 1850, green gram Rs 3250, moth bean Rs 2875, cluster bean Rs 1775 and pearl millet Rs 725) and straw (pearl millet Rs 125, cluster bean Rs 154 and others Rs 42). The sole planting of all the intercrops was also done in the adjoining field. The four years mean yield of various intercrops in sole stands viz., green gram 677 kg, clusterbean 1353 kg, pearl millet 1853 kg, moth bean 721 kg and cowpea 691 kg/ha was used for computation of competition functions by the following methods suggested by Willey (1979). Land equivalent ratios (LER) = La+Lb, La=Yab/Yaa, Lb = Yba/Ybb where, La and Lb are land equivalent ratio of main crop and intercrop, respectively. Yaa and Yab are yields of main crop while Ybb and Yba are the yields of intercrop in sole stands and in intercropping, respectively. Area time equivalent ratio (ATER) = (LaTa+LbTb)/T where La and Lb, are partial LERs of main crop and intercrop, Ta and Tb are duration of main crop and intercrop and T is the total duration of the whole intercropping system. Income equivalent ratio (IER) = income from both main crop and intercrop in intercropping system/income from sole main crop. Monetary advantage index (MAI) = Net returns from combined produce (Rs/ha) x (LER-1)/LER. Aggressivity of main crop (Aab) = {(Yab/Yaa x Zab) - (Yba/Ybb x Zba)} and of intercrop (Aba) = {(Yba/Ybb x Zba) - (Yab/Yaa x Zab)}. Relative crowding coefficient of main crop (Kab) = (Yab x Zba)/(Yaa-Yab) Zab and of intercrop (Kba) = (Yba xZab)/(Ybb – Yba) Zba, and product of both (K) = Kab x Kba. Competitive ratio of main crop (Cra) = (LERa/LERb) (Zba/Zab) and of intercrop (Crb) =

(LERb/LERa) (Zab/Zba) where Zab, proportion of intercrop area allocated to main crop and Zba, proportion of intercrop area allocated to intercrop.

Results and discussion

Grain yield

The difference in castor yield among all the four sole planting pattern viz., 75 cm and 90 cm row spacing and 60:90 cm and 60:120 cm paired row with 60 cm plant to plant spacing was not significant. However, paired row planting had slight advantage over single row planting pattern with yield gain of 6.4 per cent (Table 1). This may be due to more solar radiation interception in paired row planting as compared to sole planting. Similar results were also reported by Kumar (2002). In 60:90 cm paired row system, intercropping of 1 row of cluster bean, cowpea and pearl millet decreased the yield of main crop (castor) significantly, whereas, in 60:120 cm paired row planting, intercropping of 2 rows of all intercrops decreased castor yield significantly. However, it was interesting to note that productivity of the castor based intercropping systems in terms of total as well as castor equivalent yield was higher than sole castor planting patterns.

In respect to castor equivalent yield, intercropping of 2 rows of green gram in 60:120 cm paired row and 1 row of green gram in 60:90 cm paired row of castor were at par but both these systems were superior to all other intercropping systems. Porwal *et al.* (2006) and Srilatha *et al.* (2002) also reported similar findings. Intercropping of 1 row of green gram in 60:90 cm and its 2 rows in 60:120 cm increased castor equivalent yield by 62.0 and 73.1 per cent over sole castor planting at 75 cm and 90 cm and 52.4 and 62.6 per cent over 60:90 cm and 60:120 cm paired row planting patterns, respectively. Also intercropping of moth bean, cowpea and cluster bean either 1 row in 60:90 cm and 2 rows in 60:120 cm paired row of castor were at par to each other but superior than intercropping of pearl millet in castor and pure planting patterns of castor. Legume intercrops might have improved nitrogen status of the soil on account of atmospheric N-fixation which was utilized by castor after harvest of legumes. However, even intercropping of 1 and 2 rows of pearl millet was significantly better than sole planting of castor in both single and paired row planting of castor. Though the castor + pearl millet intercropping system was most productive in terms of total yield but it had the lowest castor equivalent yield owing to low price of pearl millet grain i.e. Rs 725 /100 kg.

Economics

Castor planting in 60:90 cm and 60:120 cm paired row had significantly higher net returns to the extent of Rs 874 and Rs 710 as compared to 75 cm and 90 cm row to row planting of castor (Table 1). All the intercrops in both the paired row planting pattern of castor were more economical than sole planting of castor. Intercropping of 2 rows of green gram in 60:120 cm castor paired row system gave significantly higher net returns (Rs 9674/ha) and B: C ratio (1.63) as compared to all other intercrops in both the planting pattern of castor as also observed by Dhimmar (2009) and Prasad *et al.* (2011). Also, intercropping of 1 row of green gram in 60:90 cm paired row planting of castor was found significantly more economical (Rs 8499/ha) as compared to remaining intercrops in both the planting patterns of castor. Among all the intercrops, the pearl

Table 1: Effect of plant geometry and intercrops on grain yield of castor, castor equivalent yield and economics of castor intercropping system (pooled data of four years)

Planting system	Grain yield (tonnes/ha)					Castor equivalent yield (tonnes/ ha)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
	2006	2007	2008	2009	Mean					
Castor at 75 cm	0.65	1.19	0.74	0.58	0.79	0.79	13 543	14 615	1 072	1.07
Castor at 60:90 cm	0.72	1.25	0.78	0.63	0.84	0.84	13 668	15 614	1 946	1.14
Castor at 60:90 cm + 1 row of green gram	0.67 (0.33)	1.18 (0.25)	0.70 (0.27)	0.54 (0.20)	0.77 (0.26)	1.28	15 144	23 643	8 499	1.56
Castor at 60:90 cm + 1 row of moth bean	0.69 (0.37)	1.15 (0.15)	0.68 (0.18)	0.51 (0.12)	0.76 (0.21)	1.11	15 122	20 479	5 357	1.35
Castor at 60:90 cm + 1 row of cluster bean	0.63 (0.26)	1.11 (0.33)	0.65 (0.31)	0.49 (0.25)	0.72 (0.28)	1.04	15 063	19 295	4 232	1.28
Castor at 60:90 cm + 1 row of cowpea	0.65 (0.34)	0.99 (0.17)	0.58 (0.21)	0.43 (0.15)	0.66 (0.22)	1.06	15 037	19 573	4 536	1.30
Castor at 60:90 cm + 1 row of pearl millet	0.62 (0.77)	0.73 (0.94)	0.43 (0.75)	0.28 (0.69)	0.51 (0.79)	0.95	14 995	17 649	2 654	1.18
Castor at 90 cm	0.67	1.17	0.73	0.57	0.78	0.78	13 460	14 522	1 062	1.08
Castor at 60:120 cm	0.73	1.21	0.76	0.60	0.83	0.83	13 509	15 281	1 772	1.13
Castor at 60:120 cm + 2 rows of green gram	0.55 (0.40)	1.07 (0.32)	0.63 (0.35)	0.46 (0.29)	0.68 (0.34)	1.35	15 245	24 919	9 674	1.63
Castor at 60:120 cm + 2 rows of moth bean	0.59 (0.43)	1.03 (0.17)	0.60 (0.22)	0.44 (0.16)	0.66 (0.25)	1.11	15 290	20 525	5 235	1.34
Castor at 60:120 cm + 2 rows of cluster bean	0.53 (0.39)	0.99 (0.42)	0.58 (0.41)	0.42 (0.35)	0.63 (0.39)	1.07	15 279	19 887	4 608	1.30
Castor at 60:120 cm + 2 rows of cowpea	0.54 (0.41)	0.86 (0.22)	0.50 (0.30)	0.34 (0.34)	0.56 (0.29)	1.09	15 263	20 165	4 902	1.32
Castor at 60:120 cm + 2 rows of pearl millet	0.51 (1.04)	0.59 (1.19)	0.35 (0.92)	0.18 (0.86)	0.41 (1.00)	0.96	15 181	17 686	2 505	1.16
CD (P=0.05)	0.10	0.15	0.10	0.13	0.12	0.09		1442		

Figures in parenthesis indicates the grain yield of intercrops

Table 2: Biological parameters in different castor based intercropping systems (mean of four years)

Intercropping system	LER	ATER	MAI	IER	A_C	A_i	CR_C	CRi	K_C	K_i	K
Castor at 60:90 cm + 1 row of green gram	1.30	1.10	1961	1.61	0.52	-0.52	1.02	0.98	4.59	1.46	6.70
Castor at 60:90 cm + 1 row of moth bean	1.18	1.00	817	1.40	0.54	-0.54	1.34	0.74	3.73	0.94	3.50
Castor at 60:90 cm + 1 row of cluster bean	1.06	0.98	240	1.32	0.55	-0.55	1.74	0.57	2.44	0.62	1.51
Castor at 60:90 cm + 1 row of cowpea	1.11	0.93	409	1.34	0.46	-0.46	1.06	0.94	1.59	1.09	1.73
Castor at 60:90 cm + 1 row of pearl millet	1.03	0.77	77	1.20	0.30	-0.30	0.61	1.63	0.66	1.72	1.14
Castor at 60:120 cm + 2 rows of green gram	1.32	1.06	2345	1.71	0.25	-0.25	1.23	0.81	3.41	1.33	4.53
Castor at 60:120 cm + 2 rows of moth bean	1.15	0.94	683	1.41	0.31	-0.31	1.75	0.57	3.07	0.70	2.15
Castor at 60:120 cm + 2 rows of cluster bean	1.06	0.95	261	1.37	0.31	-0.31	1.98	0.50	2.47	0.54	1.33
Castor at 60:120 cm + 2 rows of cowpea	1.10	0.87	446	1.38	0.21	-0.21	1.20	0.83	1.60	0.97	1.55
Castor at 60:120 cm + 2 rows of pearl millet	1.04	0.71	96	1.21	0.05	-0.05	0.69	1.45	0.74	1.57	1.16

LER, Land equivalent ratio; ATER, area time equivalent ratio; MAI, Monetary advantage index; IER, Income equivalent ratio; A, aggressivity; CR, competitive ratio; K, relative crowding co-efficient; c, castor; i, intercrops.

millet intercrop was found least economical in both the planting patterns owing to lower market price of the pearl millet grain. Highest monetary advantage index (2345) and income equivalent ratio (1.71) were obtained with intercropping of 2 rows of green gram in 60:120 cm castor paired row system followed by intercropping of 1 row of green gram in 60:90 cm paired row planting of castor with monetary advantage index of 1961 and income equivalent ratio of 1.61 (Table 2).

Competition functions

Land equivalent ratio (LER) of various intercropping systems varied from 1.03 to 1.32 (Table 2) but area time equivalent ratio (ATER) was greater than unity only when either 1 or 2 rows of green gram were taken in castor paired row planting at 60:90 cm or 60:120 cm. In all other intercropping systems, ATER values were less or equal to unity (0.71 to 1.0) indicating that except green gram the other intercrops viz., moth bean, cluster bean, cowpea and pearl millet could not utilize available land and space properly with respect to time in association with castor crop. Higher values of LER and ATER in castor + green gram intercropping systems reflect development of complimentarity between the two crops with least competition in these systems. All the intercropping systems were advantageous than sole castor planting systems because the product of relative crowding coefficient of main crop and intercrop was more than one due to their complimentary relationship (Table 2). The higher values of relative crowding coefficient of castor obtained from intercropping of 1 row of green gram either in 60:90 cm (4.59) or 2 rows (3.41) in 60:120 cm paired rows of castor indicated greater advantage from these intercropping combinations which was further evident from their respective higher values of product crowding coefficient of 6.70 and 4.53, as also reported by Tuti *et al* (2012).

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Interventions for better livelihoods and readiness of irrigated farming communities under climate change

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Abstract

The recent report of the Inter-Governmental Panel on Climate Change confirmed again that the climate variability and change impacts will be felt globally, but the dry areas will be particularly more affected. The first impacts are already being felt: scarce natural resources are further depleted; temperature extremes are affecting crop and livestock productivities; and droughts have become more severe and frequent. Crop varieties grown today may not produce sufficient yields in the changed climate of tomorrow. Better adapted, more stress-tolerant varieties, and new crops and cropping patterns, will be critically needed. Furthermore, climate models predict that the total area of cultivable land in dry areas will decrease or shifted. Together, these factors will exacerbate food security problems in most developing countries in the dryareas. Through a regional project funded by The International Fund for Agricultural Development (IFAD), several interventions that are adequate to specific agroecologies and local communities are being evaluated in Egypt, Sudan, Eritrea, Ethiopia, and Yemen. The overall objectives are to help up-surging the resilience of small farmers to climate change impact on water supply availability; improve food and feed availability; and improve the livelihoods of farmers. These interventions include new improved, water efficient, and multi diseases tolerant cereal and legume cultivars, improved water and irrigation technologies as well as better integrated crop-livestock management approaches.This paper reports preliminary results of introducing improved wheat cultivars on raisedbed technology as an intervention in Assiut Governorate of Upper Egypt and improved wheat cultivars and early sowing date in lower Atbara area of Sudan. The interventions at the farmers' field in Egypt yielded water saving on average 25% and increased wheat yield up to 24% compared to the farmers' traditional practices. While in Sudan, farmers obtained an increased wheat yield by 144% with the same amount of applied irrigation water at the reference site. Some economic outcomes reported by the authors suggest a set of proposed interventions to be pursued in attempts to achieve a triple wins: cope with climate change, improve food security, and improve the livelihoods of poor-resource's farmers of dryareas.

Introduction

Agriculture is the predominant user (75-85%) of the available freshwater resource in many parts of the world including Egypt and Sudan at even higher portion to reach 97% (http://thewaterproject.org/water-in-crisis-sudan.asp). Although worldwide, irrigation provides only 10% of agricultural water use and covers about 20% of the cropland, it can vastly increase crop yields, improve food security and contribute 40% of total food production since the productivity of irrigated land is three times higher than that of rainfed land. FAO predicts a net expansion of irrigated land of some 45 million hectares in 93 developing countries and projected that agricultural water withdrawals will increase by approximately 14% during 2000-2030 to meet food demand. Agriculture will continue to be the largest consumer of the earth's freshwater and as water resources shrink and competition for water from other sectors grows, the agriculture sector is forced to producing more food of better quality while using less water and ensuring environmental sustainability (http://

www.fao.org/newsroom/en/focus/2006/1000252/index.html). This makes it necessary to shift agriculture production indicator from land productivity to water productivity (WP). Although there is no global agreement for a unique definition for water productivity (Barker *et al.* 2003; Molden and Oweis 2007), the widely accepted definition and in this paper is crop yield per cubic meter of water consumed.

Innovative climate change-proof production systems package to include improvement to water productivity is a model developed to increase the resilience and better livelihoods of the rural poor in the developing world are critically needed. Most of the developing countries of the dry areas face the challenge in achieving sustainable growth which is getting even more problematic by the constraints the agricultural sector is facing. Renewable water resources are limited. Rainfall is unpredictable and highly variable, and this short-term variability is likely to be exacerbated by longer-term climate changes. Historical evidence shows that both natural and managed ecosystems in the dry areas face substantial adverse impacts due to existing climate variability, resulting in changes by longer-term climate changes which have a great effect on current and future agriculture. It may bring further risks due to global warming and possible aridity (FAO 2013). Despite the increase in water productivity by at least 100% between 1961 and 2001 due to yield increase of some crops e.g. rice and wheat, it is predicted that additional water development will be needed in order to accommodate the needs of another 2 billion people in the world by 2030 (FAO 2003; Fereres 2004).

Dissemination of the model; proven agriculture production systems' packages; has been a major interest of the agricultural research and extension systems. The success in the adoption rate, however, accounts only for one-third of the target farming communities in the region. Three key reasons for the slow adoption rate can be offered. These are limitation of no economic gains from the adoption, the limited effectiveness of extension services, and the absence/marginal existence of business enterprises involved in the technology transfer.

In the Nile Valley and Sub-Saharan African countries, the ever-increasing demand for food is extending the boundaries of agriculture production to nontraditional areas, mainly to hotter and dryer areas. For example, food production is expanding to nontraditional farming areas, such as areas northwest of the delta and the new valley in Egypt. Similarly, in Sudan the food production area is expanding to high terraces of the Northern States and in Ethiopia the government plan is enhancing the expansion of wheat production to nontraditional areas in the lowlands.

Furthermore, raising agricultural productivity requires filling the yield gaps at farmers'fields relative to the yield achieved in the research trials and demonstrations that work on a new better adapted varieties and production packages capable of improving and stabilizing yields despite droughts, heat, and major disease and insect pests. Moreover, these packages need to ensure higher water and other inputs use efficiencies. To do just that, a project entitled *Improving the Livelihoods of Rural Communities in the Nile Valley and Sub-Saharan Africa Region: Sustainable crop and livestock management* was implemented in five countries, namely Egypt, Eritrea, Ethiopia, Sudan and Yemen, funded by IFAD. The project targeted resource-poor farmers and agro-pastoralists, and communities in the dry areas who depend solely on agriculture and related activities for their livelihoods. The project focused on processes that empower communities and their members, particularly poor households and women, enabling them to manage and use their resources more effectively and sustainably, and to reduce their vulnerability to climate changes. This paper is presenting some preliminary results from introducing technology of growing improved wheat cultivars on raised-beds as an intervention in Assiut Governorate of Upper Egypt and improved wheat cultivars and early sowing date coupled with recommended agronomic interventions in lower Atbara area of Sudan.

Egypt

Agriculture is a dominant contributor to economic growth in Egypt, accounting for approximately 15 percent of the country's USD 232 billion Gross Domestic Product (GDP). Moreover, around 55 percent of the population is dependent on the sector for its livelihood, and agriculture generates close to 36 percent of Egypt's total employment (MALR 2010).

Food security is one of the main concerns of the Egyptian government. However, the current situation of food production is far below the needs. Therefore, Egypt has to import most of its needs of some strategic crops to achieve food security. Imports of wheat represent about 50% of its needs. Assisting farming communities to improve their livelihoods and to cope with and adapt to climate variability and change risks, Assiut Governorate of Egypt (Fig. 1) was taken as an entry model for this Project due to its low productivity in relation to the potential, land fragmentation, and poverty level of the farming communities.

Figure 1: Assiut Governorate of Egypt.

Assiut Governorate stretches for about 120 km along the bank of the Nile and accounts for 2.6% of total area of Egypt, and has a population of around 3.5 million people, 63% of whom live in rural areas. The total cultivated area in Assiut is about 70,000 ha. According to the available data of cropping pattern in Assiut, wheat accounts for 56% of cultivated area in winter followed by clover (32% of cultivated area) for animal feed. In summer, 27% of the cultivated area is under cotton, followed by sunflower (21% of cultivated area). However, sorghum occupies 17% and maize 12 % of total cultivated area in summer. These two crops give byproducts for animal feed in summer while clover is the main animal feed in winter in addition to mixture of wheat bran and meshed yellow corn. Also, there are 12 vegetable crops planted on about 3,600 ha in winter where tomatoes represents 76 % of this area followed by cabbage (6%)and the other 10 crops (18%). In addition, four medicinal and aromatic crops are grown in small areas.

The diversity in cropping pattern in Assiut Governorate helped the project in applying field interventions to sustain good crop production with maintenance of soil fertility. The interventions focused on addressing the priority constraints verified by farmers during a Participatory Rapid Appraisal (PRA) baseline and need assessment survey conducted during the first six month of Project implementation. The priorities identified included the need for: (i) improved crop rotation associated with enhanced production technology packages; (ii) water use efficiency management practices; (iii) and improved animal production practices.

For crop rotation, the objective is to gradually replace the prevailing inefficient, low productivity, soil fertility depleting mono-cropping system, dominated by wheat and clover in the winter growing season and maize and sorghum in the summer growing system, by a more efficient, soil fertility improving and higher productivity and income diversifying cropping systems based on rotating a wide range of winter and summer crops based on farmers' preferences and market prices. The new crops introduced in the rotations in the winter growing season included sugar beet, faba bean, fenugreek, onion, and caraway. For summer growing season, the newly introduced crops are soybean, peanut, cowpea, cabbage and cucumber.

For improved crop production, the technology packages combined high yielding and heat tolerant varieties, improved seed rates and seeding practices, optimum planting time, fertilizer application, weed and pest control, and optimal irrigation regime. The improved technologies being tested, as an example, for wheat included application of 75 kg/ha of phosphorus (P_2O_5) at the time of land preparation, row planting every 10 cm on 120 cm broad raised beds, optimum date of planting, seed rate, nitrogen fertilizer (N) rates, irrigation regime and weed control in line with the recommendations released by research.

For water productivity enhancement, the objective is to develop optimum water management practices based on accurate crop water requirements and evaluated in terms of productivity of grain per m^3 of irrigation water. The work included a comparison in water saving and water use efficiency between raised-bed and flat planting for maize and wheat.

Results achieved in Egypt

The crop rotations tested in 20 farmers demonstration trials during 3 years are presented in Table 1. All rotations started with a wheat crop in the first winter growing season (2010-2011) and a maize crop in the first summer growing season (2011). As of the second year, the wheat mono-cropping cycle for winter crops and the maize mono-cropping cycle for summer crops started to be gradually replaced by new cash crops.

The gradual shift from mono-cropping to more diversified cropping patterns for both winter and summer crops are relevant and technically sound. The newly introduced crops have the potential to reduce mono-cropping risks, provide substantial incremental cash income and offer through

Table 1: New crop rotations introduced - Egypt

Winter crop rotations			Summer crop rotations		
2010-2011	**2011-2012**	**2012-2013**	**2011**	**2012**	**2013**
Wheat	Clover	Clover	Corn	Corn	Sorghum
Wheat	Clover	Wheat	Corn	Corn	Peanut*
Wheat	Sugar beet*	Wheat	Corn	Sorghum	Sorghum
Wheat	Faba bean *	Sugar beet*	Corn	Cowpea*	Cabbage*
Wheat	Clover	Sugar beet*	Corn	Sorghum	Cowpea*
Wheat	Onion *	Clover	Corn	Soybean*	Corn
Wheat	Caraway*	Clover	Corn	Peanut*	Sorghum
Wheat	Fenugreek*	Wheat	Corn	Cabbage*	Cucumber*

*Newly introduced crops

Table 2: Production under improved technology in 2011 and 2012 field trials in Egypt

Crop	Neighboring farm	Demonstration field	
	Yield (t/ha)	**Yield (t/ha)**	**Yield increase**
Summer 2011			
Maize (20 trials)	7.56	9.28	22.75%
Winter 2011-2012			
Clover (12 trials)	68.6	91.1	32.80%
Faba. Bean (3 trials)	2.59	2.81	8.49%
Sugar beet (1 trial)	8.66	10.71	23.67%
Wheat (13 trials)	6.07	7.5	23.56%
Onion (1 trial)	54.7	59.5	8.78%
Fenugreek (1 trial)	3.75	4.28	14.13%
Caraway (1 trial)	1.43	1.55	8.39%
Summer 2012			
Soybean (1 trial)	5.62	6.05	7.65%
Peanut (1 trial)	3.07	3.24	5.54%
Cucumber (I trial)	8.84	9.6	8.60%
Dry bean (1 trial)	2.16	2.28	5.56%

their by-products a valuable source of additional animal feed. In parallel to the above crop rotation work, on-farm field trials have been conducted consecutively from 2011 to 2013 with the same 20 participating farmers to test and evaluate the improved production technologies. The results in terms of yield in comparison with neighboring farmers are presented in Table 2, for two summer growing seasons (2011 and 2012) and one winter seasongrowing season (2011-2012).

Focusing on wheat crop, compared to the neighboring farmers practices, the improved technologies demonstrated on farmers' plots increased the average yield for all crops. For winter crops, yield increases were higher for the traditional crops (30% and 24% respectively for clover and wheat) compared to newly introduced crops with an increase of 8% for caraway and onion, 14 % for fenugreek and 23% for sugar beet. For summer crops, the yield increase was also higher for maize with 22 % increase compared to newly introduced crop with an increase of 5% for peanut, 6 % for dry bean, 9 % for cucumber and 10% for soybean.

Raised-bed row planting technology for water productivity (WP) improvement was evaluated in 13 demonstration trials on farmers fields; the average 1.5 kg of wheat production per m^3 of water under raisedbed row planting technology exceeded by 47% the average of 1.01 kg of wheat production per m^3 under traditional flat planting. In the 20 demonstration trials on maize, the average 1.6 kg maize produced per m^3 of water under the raised-bed row planting technology exceeded by 23 % the average 1.3 kg maize production per m^3 of water under the traditional flat planting practice. Thus, the raisedbed row planting practice resulted in 25 % average irrigation water saving per ha compared to the flat planting system. Rough calculations for the entire wheat growing area of Egypt (about 1.3 million ha) indicated that this technology could save more than 1.6 billion m^3 per year.

Sudan

The agricultural sector is the most important economic sector in the country. It created 39% of the GDP, employed about 80 percent of population, and contributed 80 percent of the country's exports in the late 1990s. Cotton is the main agriculture export item, although export volumes have been decreasing lately. Furthermore, the agricultural sector of Sudan has suffered more during the last two decades due to sanctions and civil war, resulting in reduced food sufficiency ratio and outmigration of many of rural communities.

Figure 2: Lower Atbara Region of Sudan.

The intervention site for this Program in Sudan is selected to target four of twelve villages in Lower Atbara River region of the River Nile State in northeastern Sudan (Fig. 2) covered by an on-going IFAD loan funded Integrated Rural Development Project in the region. River Nile State has an area of 122,123 km² and an estimated population of 1,027,534 (http://en.wikipedia.org/wiki/River_Nile_%28state%29).

The selected site combined crops of winter season, which is the main production season in the State with full irrigation where water is pumped from the river and shallow wells (*mataras*), and crops of summer where farmers rely mainly on shallow wells (*mataras)* for irrigation water. This site is representative of a wide arid zone area characterized by erratic and low rainfall of less than 100 mm per year. Farmers are exposed to risks from climate change in variability in addition to seasonality of surface water from Atbara River, limited groundwater resources, poor irrigation efficiency, low agriculture productivity, wind erosion, and depleting pastoral resources.

The program interventions focused on the priority adaptive research themes expressed by farmers through the PRA base line and need assessment survey conducted during the first six month of Project implementation. These priorities are: (i) enhanced crop productivity of winter wheat and faba bean as traditional crops, and introduction of chickpea and common bean as new cash crops; (ii) small-scale irrigation water saving schemes; and (iii) enhanced livestock productivity.

For crop production, the identified technology packages combined improved cultivars, optimum planting time, seed rate and fertilization, irrigation regime, and weed and pest control management practices. The technologies have been demonstrated in on-farm trials (OFT) from 2011 to 2013 with several farmers in the targeted four villages. For wheat, 2 early and 3 late maturity varieties and for faba bean, 3 improved varieties have been tested. The late maturity varieties are resilient to terminal heat stress. For comparison purpose, the traditional neighboring farmers' practices (NFP) for wheat and faba bean were monitored and referenced on-station trials (OST) have been established for each crop at Hudeida regional ARC research farm. For chickpea and common bean, newly introduced crops, the comparison has been between on-farm and reference on-station trials. The characteristics of the technology packages being tested are presented in Table 3.

Table 3: Crop production technology packages tested in Sudan

Crop	**Improved crop production technology packages**
Wheat	Use of high yielding heat tolerant early and late maturity varieties; early planting; use of 140 kg of seed per ha, 43 kg/ha of phosphate (P2O5) at land preparation, 130 kg N/ha; chemical and hand weeding to control weeds; 8.5 irrigations at OFTs.
Faba bean	Use of the high yielding varieties; early planting; application of 120 kg/ha of seed, chemical and hand weeding; 7 irrigations at OFT and 10 at OST.

Results achieved in Sudan

The results of 2011-2012 winter growing season presented in Table 4. In comparison with neighboring farmers' practices (NFPs), the improved technology packages for wheat at on-farm trials (OFTs) increased the average yield by 132% for Bohein, an early maturing and non-shattering variety and by 156 % for Imam a late maturing heat tolerant high yielding variety. In the reference on-station trials (OSTs), with better-controlled crop management practices, the incremental yields exceeded by 400% and 100% over NFPs and OFTs for Bohein and Imam varieties respectively. For faba beans, the improved packages increased the average yield by two-folds (205%) at OFTs and three-folds (312%) at OSTs compared to NFTs. The particularly high yield at OSTs (35% over OFTs) is due to the optimum irrigation practices (ten irrigations at OSTs versus seven irrigations at OFTs).

Table 4: Grain yield performance (ton/ha) of wheat and faba bean in demonstration plots in Lower Atbara area , 2011-2012 season

Result indicator	**NFP[1]**	**(OFT)[2]**		**(OST)[3]**	
Winter Wheat 2011-2012 crop season					
Average yield (Ton/ha)	1.16	(Bohein) 2.70	(Imam) 2.97	(Bohein) 5.79	(Imam) 6.03
Yield increase over NFP	-	132%	156%	400%	420%
Yield increase over OFT	-	-	-	114%	103%
Faba bean 2011-2012 crop season					
Average yield (Ton/ha)	0.71	2.17		2.93	
Yield increase over NFP	-	205%		312%	
Yield increase over OFT	-	-		35%	
Marginal rate of return	-	3190%		1518%	

[1]Neighboring farmers' practices; [2] On-farm trials; [3] On-station trials

Summary

The generation of improved technologies in Egypt and Sudan focused on existing staple cereal and food legume crops, forage crops and a wide range of newly introduced crops for improving crop rotations and income diversification. The technology packages combined the use of high yielding and drought and heat tolerant varieties, optimum seed rates and planting time, fertilizer, weed and pest control, and irrigation regimes and seed production and distribution systems. The interventions at the farmers' filed in Assiut Governorate of Egypt yielded a water saving for up 25%, and increased wheat yield for up to 24% compared to the farmers' traditional practices. While in Sudan, farmers obtained an increase in wheat yield in the on-farm trials by 144% over on average compared to the neighboring farmers with the same amount of applied irrigation water at the reference site; on the station level the results show even higher potential for yield increase for both wheat and faba bean (over 200%) as compared to the neighboring farmers fields. The preliminary results suggest that the proposed interventions would lead to achieving a triple win; cope with climate change, improved food security, and improved of poor-resource farmers of dry areas.

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Unlocking the poverty-environment dilemma in China's Loess Plateau: a small watershed case study

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Abstract

The Loess Plateau of northwestern China has long been facing environmental and socio-economic problems such as extensive soil erosion and chronic poverty. These issues are always interlinked and usually reinforce each other, and all pose a significant threat to regional sustainability. Moreover, it is a menace to the property and life safety of downstream reaches of the Yellow River. The situation in the gullied hilly regions (GHRs), a majority of the Loess Plateau, is even worse because of its more fragile ecosystem and heavy rural population pressure. Past single-disciplinary approach of research often resulted in feasible technologies but poor adaptability for regional development, therefore, a multi-dimensional strategy is required in finding sound solutions to these complex and interrelated challenges. A small catchment basin, Gaoquan Watershed (9.2 km^2) in hinterland of Loess Plateau's gullied hilly regions, was chosen as a research site in 1986 and multi-disciplinary research and demonstrations have been carried out with emphasis on utilizing natural resources in an integrated manner. Rain-water harvesting methods were developed to mitigate adverse effect of water shortage; slope terracing and afforestation were combined to minimize soil erosion; improved dryland farming technologies and animal husbandry were integrated to increase agricultural productivity; and biogas-centered eco-farmyard systems were introduced to build an environment-friendly rural community. Long-term (1985-2010) monitoring and observation have shown significant results in the study area. Soil erosion reduced and local farmers' income increased remarkably. Successful practices of integrated natural resource management have led this marginal semi-arid catchment basin towards sustainable development, exhibiting the possibilities of achieving sustainability in Loess Plateau's vulnerable ecosystem.

Introduction

The "poverty–environment nexus", a set of mutually reinforcing links between poverty and environmental damage, has been one of the research priorities in recent decades. The relationship between poverty and environment is quite complex and not amenable to easy generalisation. There is a big diversity of patterns and situations in different countries (Nadkarni 2000). In north-western China, the poverty-environment is inextricably linked.

The Loess Plateau, located in the north-western part of China, got its name from the thick layer of loess topsoil. Approximately 624,000 km^2 in size it includes most territory of Shaanxi, Gansu, and Shanxi provinces, and some parts of Inner Mongolia, Ningxia, Henan, and Qinghai provinces, which are all within the catchment area of the Yellow River (Fig.1).

Although the Loess Plateau is well-known worldwide for its extensive environmental degradation in the form of heavy soil erosion, local people have been much concerned about their food security and low income. Historically, the Plateau, which used to be highly fertile and required little effort for early inhabitants to farm, was one of the cradles of Chinese civilization. For more

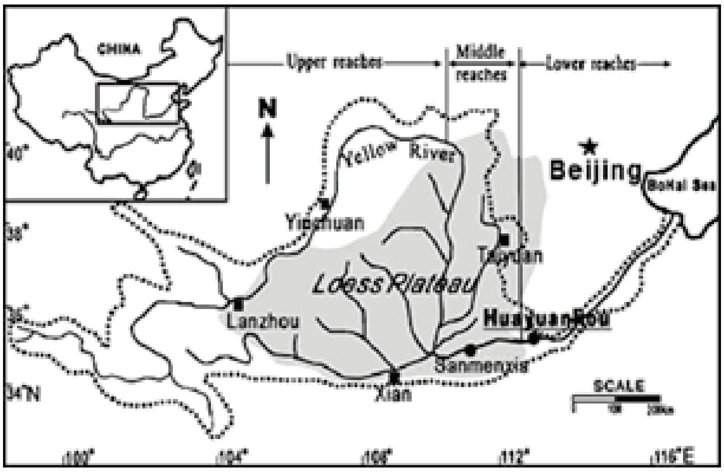

Figure1: Location of the Loess plateau, China (Chen *et al.* 2007).

than twenty centuries human impacts have chronically affected the ecological environments of the Plateau (Wang *et al.* 2010). Increased demand for food, because of rising population, has led to the erosion-prone slopes o be exploited for farming purposes. Over-overgrazing, over-farming and over-logging have led to severe soil loss on the Plateau, especially in its hilly areas (Fig. 2).

Figure 2: Typical landscape of hilly areas in the Loess Plateau (ACIAR 2006).

It is estimated that soil erosion in the hilly areas of the Loess Plateau ranges from 5000 to 10,000 ton km-2 yr-1, and in some parts it is greater than 20,000 ton km-2 yr-1 (Fu and Chen 2000). This massive soil erosion depletes nutrients in topsoil, destroys soil structure and reduces water holding capacity and, eventually, degrades soil quality and land productivity. Regionally, heavy sedimentation of eroded soil discharges into the water bodies of the Yellow River, causing the downstream riverbed rising every year, in certain places exceeding the natural elevation on its banks, and imperilling life and property at the lower reaches (Yang *et al.* 2009). Moreover, as soil has great potential to act as massive carbon sinks, erosion also causes excessive carbon release (Morgan 2005).

Serious soil erosion does not only result in environmental consequences but also generates social problems, such as food deficiency. The soil fertility on eroded land is generally low, leading to poor soil quality and less reliable harvests; while erosion also fragmentises farmland, forming deep gullies and bare slopes, which make farming operations more difficult. Famine had been the common events in the first several decades of last century, especially in the aftermath of extreme dry spells (Cook *et al.* 2000).

Regional economy in the Loess Plateau is also strongly influenced by the environmental and social drawbacks. Because subsistence agriculture has been the main occupation in the region, and few opportunities are available for off-farm employment, the region's labour force has to use the already degraded natural resources more intensively to sustain basic livelihood and, if possible, to improve household incomes. One extreme case happened in Dingxi County, Gansu Province in 1960s, where peasants had to collect most of their crop residue and uprooted almost all available vegetation (shrubs and grasses) from hillsides as firewood for cooking and heating, leaving erosion-sensitive soil surface unprotected. The majority of local people usually remain in absolute poverty due to limitations of degenerated natural resources and constrains from policy and institutional settings. All these lead the region to more fragile ecosystems. Therefore, the region is caught in a typical poverty–food-environment trap. Rapid population growth, coupled with insufficient means or incentives to intensify production, has induced overexploitation of fragile lands on steep hillsides in this region.

There is an increasing body of literature on the poverty-environment nexus (Nadkarni 2000, Dasgupta *et al.* 2005). There are categorized into two groups. The first group focuses on exploring the technology and practices to tackle the poverty-environment trap. The other group has been trying to seek the policy-institutional solutions for it. Neither of them is successful so far. Consequently, the challenge of understanding and reconciling the inextricably linked relationship between agricultural development, food security and environment in developing countries is daunting.

This case study aims to untangle the inextricable poverty-environment dilemma by analysing a multi-disciplinary development project implemented in Dingxi County, the Loess plateau for 20 years. Retrospection, documenting and analysing this two-decade-long project are important steps to enrich understandings and knowledge of the complex ecological and socioeconomic problems in the loess Plateau, and can also help to find holistic and sustainable solutions to the issues. Experiences and lessons from this process will be beneficial for designing future development plans for the region and similar places in other parts of the world.

Review of recent attempts

China's decision makers and researchers have made a great of efforts in finding effective solutions to these long-lasting problems. Apart from two sessions of large-scale multidisciplinary surveys conducted in 1950s and 1980s, a majority of research works have been implemented in single-disciplinary mode resulting in limited success (Wang *et al.* 2010; Yang *et al.* 2009).

One such attempt was advocating conservation farming based on minimized land cultivation in crop production. When this practice is applied, the farm land is protected by living plants during the growing period and by the crop residues after their harvest. Maintaining stubble on the farm land is one of the most recommended practices for soil conservation in recent years, because it maximises land cover and acts as an effective buffer layer against erosive raindrop hits or strong winds, and thus efficiently decreases soil erosion risks. The system has however not been widely accepted because of four shortcomings: a) The tendency of yield decreases in the first few years is not acceptable to famers in the arid region dominated by subsistence agriculture (He *et al*. 2010); b) Fertilizer application has to be done prior to sowing, and nutrient availability is reduced dramatically in late growing season compared with conventional methods in which supplementary fertilisation is always possible (Wang *et al.* 2007); c) The shift to new farming practices requires new types of machinery that is usually unaffordable; and d) Conservation farming requires crop residue as mulching material and this can cause fuel and fodder shortage in the area where villagers depend on the residues for these uses for want of alternatives.

Another suggestion for soil erosion control is land closure for natural rehabilitation. It is technically effective and easy to implement but, again, it is not always feasible. Unless food self-sufficiency is securely achieved, any land use option other than crop production is not practical. To certain extent, the method of land closure in this region is regarded as a waste of resources.

Past experiences have proved that mitigation of these challenges needs a holistic consideration of different objectives. Because these environmental, economic and social problems are closely interlinked, and any attempt of tackling the poverty-environment dilemma requires careful design and consideration of almost all aspects of the entire system, needing a multi-disciplinary approach in understanding and finding more feasible and practical measures (Ascher 2001).

Case study area

Gaoquan, a small watershed sized 9.17 km^2, situated in Dingxi County of central Gansu Province, the hinterland of Loess Plateau, is a sub-tributary catchment to the Yellow River. Administratively, Gaoquan is also a village community (the lowest administrative unit in China) with a total population of 1,610. Subsistence agriculture has been the main occupation in which the local villagers are engaged.

There were several explicit characteristic features of the research site in 1985 when no development project had been implemented. Environmentally, soil erosion occurred intensively in the watershed, as the baseline erosion was massive, amounting to 6,120 t/km^2, forming a high gully density of 2.9 km/km^2 (Fig. 3). Economically, due to the natural constrains such as scarce water availability, gullied hilly terrain, nutrient depleted soil, high altitude (2,056 - 2,447m), etc., the land productivity was very low as average grain yield fluctuated around 942 kg/ha^2. Because of the low agricultural productivity under rainfed conditions and lack of off-farm employment, annual per capita income in the village was only 304 Yuan. Socially, the population load was heavy on the fragile ecosystem, as population density reached 160 per km^2, causing enormous conflicts between human and nature. It is not until the end of 20th century that this area had suffered from environmental degradation, food insecurity and long-standing poverty. It can be found that Gaoquan Watershed experienced all problems typical to the Loess Plateau regions of northwest China.

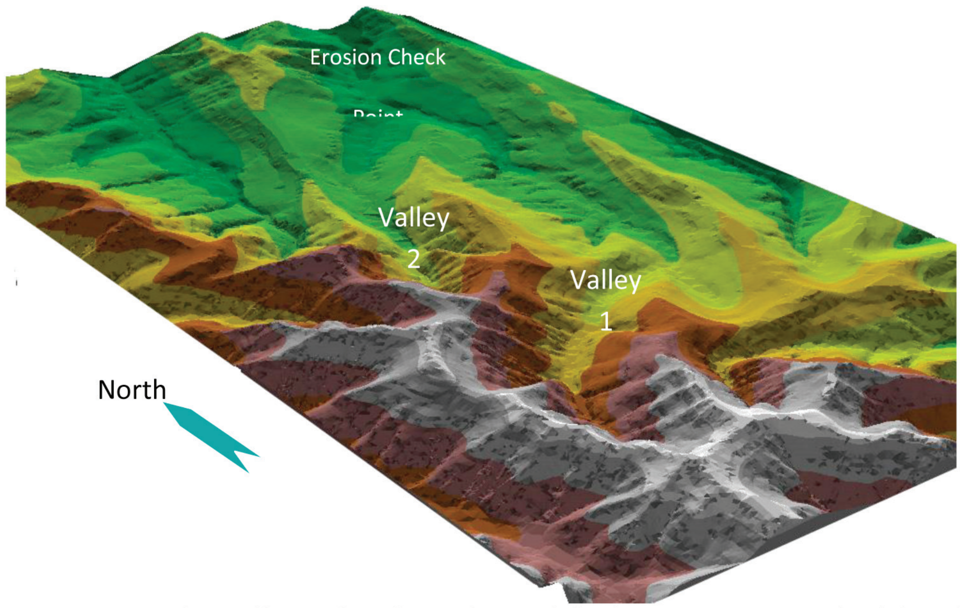

Figure 3: A three-dimensional terrain model of Gaoquan Watershed (produced by GIS Lab, GAAS).

Realising that traditional approaches were not enough for solving the complex tasks a state level research and development project was launched. The project, consisting eleven research and demonstration sites across the Loess Plateau region, began in the seventh 5-year Plan period (1986-1990), and continued for two decades till 2005. It achieved significant results at the R&D sites and beyond. Although the large scale research and demonstration project was now finished, short-term experiments and extension project are continuing at the site. Gaoquan is one of case sites of this long-term research project.

Methods

The framework used in this study integrates the perspective of technology and practice and the perspective from the policy and institution. The perspective of technology and practice starts at introducing the adopted technology then examines the effect of these technologies on tackling the poverty-environment dilemma. Similarly, the perspective of policy and institution aims to analyse the existing policy and institutions and their limitations. Importantly, the mismatch between the effective technology and the existing policy and institution is analysed. This is the basis for improving the existing policy and institution in the future. The method used in this study is shown as follows (Fig. 4).

Results

5.1. Technical approaches

According to landscape heterogeneity of Gaoquan Watershed, namely, slope and valley area, farm land area, and country road and yard area, three types of measures were put forward for different areas, forming a systematic land resource management scheme (Fig. 5).

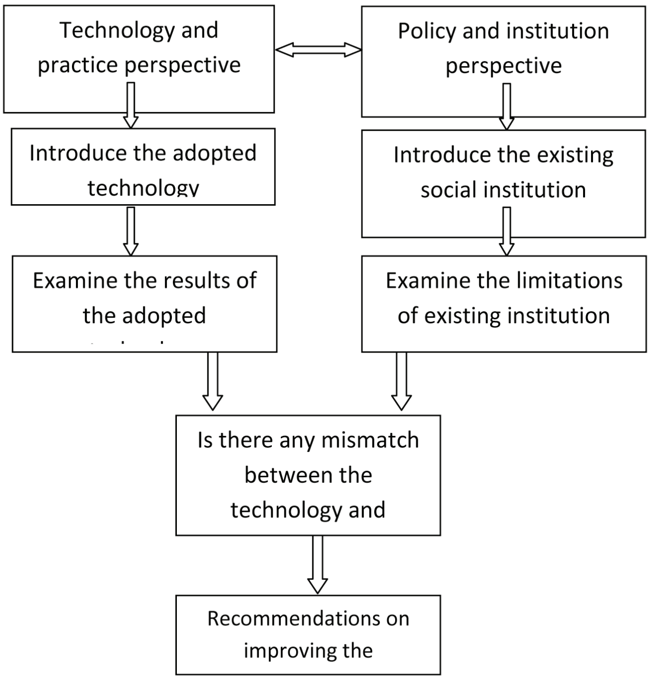

Figure 4: The framework for analysing the effects of the long-term research project in the case study area on tackling the poverty-environment dilemma.

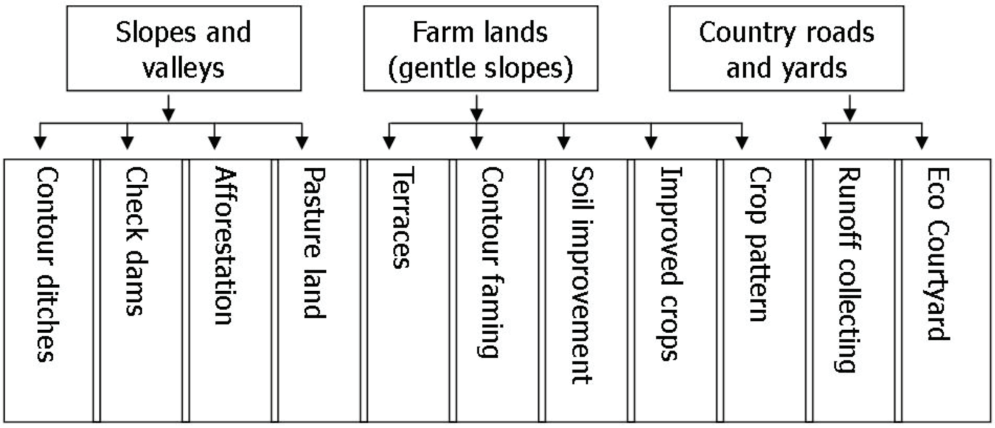

Figure 5: Technical scheme of land resource management in Gaoquan Watershed.

In slope and valley area, conservation works such as contour ditches and check dams were constructed to regulate runoff; and selected varieties of grasses, shrubs and trees were planted on steep slopes (above 15 degrees)and valleys to provide land cover. All these measures aimed at restoration of degraded ecological environment.

Farm land area is the important base for food production, where slopes are usually gentle (less than 15 degrees); the main strategy used was slope-land terracing, contour farming, fertilisation application, crop variety improvement, and crop pattern optimisation (intercropping, grain-alfalfa rotation, etc.). These measures had positive effect yield and its stability.

System was widely established to harvest rainwater from house roofs, courtyards and paved roads for domestic use and supplementary irrigation. Simplified solar-energy heating devices and bio-gas systems were installed to offset fuel shortage. Small-sized household-based industries (e.g. animal husbandry) were introduced for better use of resources and more financial gains.

These measures constitute a series of techniques forming a watershed-scale environment management system that takes most of natural and economic factors into consideration. Among these the most important technological achievements are rainwater harvesting system that focuses on water resources management and terrace construction that mainly deals with soil management problems.

Rainwater harvesting: Water resources have vital ecological and socioeconomic functions in the Loess Plateau. River water and ground water are usually unavailable in most parts of the region, and rainfall plays an extremely important role by influencing farming practices and affecting erosion patterns. Although the watershed rainfall averages only 415 mm a year, up to 40% of this annual precipitation falls in a single storm. Concentrated rainstorms cause tremendous erosion. Moreover, approximately 60% of the annual precipitation occurs in the three months between July and September (Fig. 6), which is not the period when crops need that much water. Farmers of the region have to find solutions to cope with these quantitative and temporal problems of moisture deficits by employing a variety of cultivation techniques to promote infiltration and store rainwater in the soil profile for better crop production.

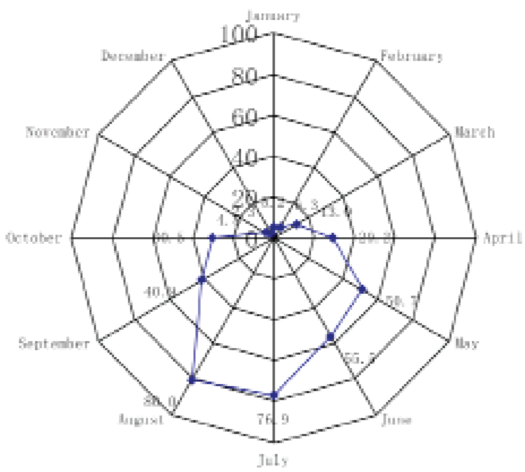

Figure 6: Monthly precipitation distribution at Gaoquan Watershed (20 year average in cm).

One strategy to offset the quantitative and temporal mismatch between water resources and crop growth is the use of rainwater harvesting. Although rainwater harvesting has been used for centuries in northwest China to meet household water needs, the technology innovation on it both for household use and for irrigation is a recent breakthrough in dryland farming, the latter is called Rain Harvesting Agriculture (RHA). RHA consists of a synergistic combination of techniques involving collecting the rainwater from a larger catchment area (roads, courtyards and artificial catchments) onto a smaller cultivated area, or in a storage structure and then using it for supplementary irrigation on farmland during dry periods. Some in-depth research results have been published since 1990s (Cook *et al.* 2000; Zhao *et al.* 2009; He *et al*. 2007; Li *et al.* 2004; Tian *et al.* 2003). As the birthplace of RHA, the Gaoquan Watershed has witnessed wide construction and management of RHA system (Fig. 7). RHA has demonstrated a great potential in regulating soil moisture and hence increasing agricultural productivity. Harvesting rainwater for farming purposes brought about ecological benefits along with economic development. RHA as an alternative method of managing rainwater resources reduces the possibility of soil erosion by gathering runoff from slopes which, otherwise, can cause soil loss and environmental damages.

Figure 7: Rainwater harvesting system in Gaoquan. (Photo: D. Zhang 2004)

Slope land terracing: Like in other places on the Loess Plateau, the soils in most parts of Gaoquan Watershed are homogenous and highly porous, which are easy to farm and have a potential of high productivity. But, on the other hand, the land is very sensitive to water erosion because of slopes and frequent rainstorms. Terracing, an engineering method that grades hillsides land into a series of flat benches, provides the possibility of maintaining crop yield while conserving land resources (Zhang *et al*. 2006). Conversion of slope lands into terraces requires newly updated agricultural techniques to optimise productivity. A series of improved farming measure has been adopted in Gaoquan. Soil amendment is extremely necessary, especially for the first several years in restoring reduced nutrients in the topsoil; for example, adding more organic fertilisers, such as manure, and increased amounts of commercial phosphate into the newly-formed fields to improve soil quality. Water management is also vital for maintaining desired grain output on terraces. For instance, mulching measures (traditional sand or crop-residue mulching or modern plastic mulching) prevent evaporation and increase water availability thus increase crop yields.

The continuous construction of terraces in Gaoquan watershed has changed local landscape (Fig. 8) with positive on-site and off-site environmental and economic benefits. The long-standing problem of food shortage was eased as a result of developing terraces for crop production. The increased available soil moisture and improved nutrients retention on terraced land, combined with improved farming management practices resulted in grain yield increase.

5.2. Results from the adopted technologies

After an unremitting effort of twenty years, the research and demonstration work in Gaoquan Watershed has resulted in significant environmental and socioeconomic outcomes. Environmentally, vegetation cover increased from 23% in 1985 to over 52% in 2006, changing landscape remarkably (Fig. 9) while soil erosion rate reduced from 6,120 ton y^{-1} km^{-2} in 1986 to less than 300 ton y^{-1} km^{-2} after 2002 (Fig. 10). Economically, local farmers' annual per capita income increased dramatically from 237 Yuan in 1985 to 2830 Yuan in 2010, which was regarded as a great achievement by local standard. Socially, food sufficiency has been achieved with annual per capita grain production of over 600kg since 2000. Successful practices of the multidisciplinary and integrated approach led this marginal semi-arid catchment basin towards promising sustainable development.

Figure 8: Terraced land in Gaoquan Watershed. (Photo: S. Gao 2005).

Figure 9: Landscape views in Gaoquan Watershed in 1986 and 2006. (Photos: X. Wu & D. Zhang).

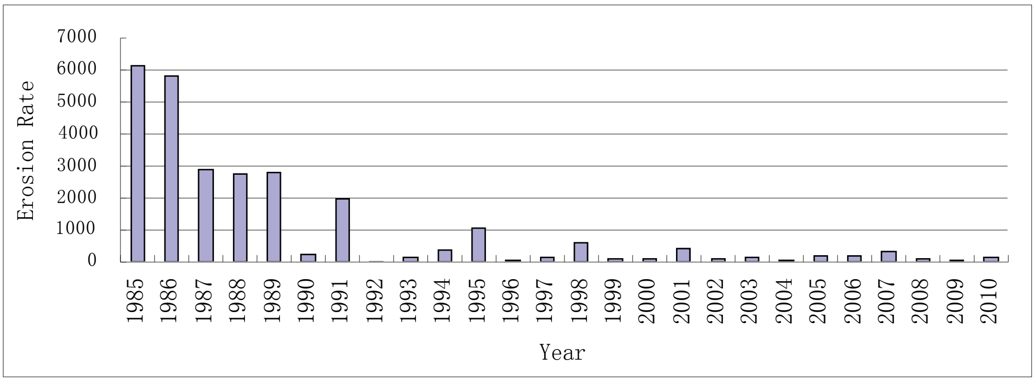

Figure 10: Long-term annual erosion rate ($t \cdot km^{-2} \cdot a^{-1}$) in Gaoquan Watershed.

5.3. Existing policy and institutional analysis

Case study in Gaoquan Watershed clearly exhibits the possibility and viability of mitigating the poverty-environment dilemma and achieving sustainability in Loess Plateau's vulnerable ecosystem. Although the success at the research and demonstration watershed offers a positive showcase for other marginal semi-arid catchment basins, its experiences and approaches have not been widely applied in other places. Scattered lessons and experiences indicate that the efficiency of conservation technology extension has not been as satisfactory as expected (Chen *et al*. 2007, Zhao *et al.* 2010, Yang *et al.* 2009). This is reflected by the water authority's report on soil sedimentation observations, which reveal that soil erosion is still a serious problem on the Plateau (Yellow River Conservancy Commission 2009).

This worrisome situation calls for careful examination of current policy and institutional arrangements related to the regional sustainability. Because a catchment (or watershed) nowadays is not only a biophysical entity, but is also socially constructed, it has, therefore, got to be understood in a broader socioeconomic context (Ison 2007).

Mismatch of land management priorities between policy makers and local land users is the main socioeconomic reason of the dilemma. As China's rural reform took place in late 1970s, the region's economic system gradually shifted from relatively closed and self-sufficient subsistence agriculture to more market-oriented economy. This provided a new socioeconomic background for considering degraded land restoration strategies and land use priorities by different stakeholders.

Land management authorities pay more attention to macro objectives in the Loess Plateau region aiming to minimise external costs, and ecological and environmental targets are, therefore, strongly emphasized. The state and local governments have been tirelessly promoting and supporting environment-friendly farming practices and land use patterns for rehabilitation of degraded land resources, regional development and, most importantly, ensuring downstream safety caused by soil sedimentation. Tree planting and grass growing have been listed as top priorities in the Loess Plateau's integrated catchment management schemes.

However, at the household level, farmers in the regions generally take into account the internal costs rather than the entire costs in decision making on land use and management. The "rational" strategy is, therefore, to use their lands for maximized food security and economic benefits.

Under the current semi-subsistence economic conditions this is reflected by farm land use structures. Farmers usually specify a certain area of land for food production while using the rest for growing cash crops, fruits production and other high value purpose use. Grass growing and tree planting that either have low market value or take long period for recovery of investment are least considered.

The problem of environmental and socioeconomic conflict still exists. Successfully restored environment and local sustainablity are not institutionally ensured, and the public lands are especially vulnerable. The essence is that the externalities of environmental degradation do not always enter household's utility function of land management decisions.

5.4. Institutional failure in existing socioeconomic systems

Complexity of poverty–environment issues demands an approach in which ecological, economic and social factors are considered. Past experiences have shown that any sustainable and responsible solutions to environmental challenges have to be compatible with acceptable livelihood and social outcomes. In another words, political and economic strategies are the key issues when environment pressure is interlinked with economic and social problems (Toscano 2007; Barry *et al.* 2008).

Some key issues that influence farmers' decisions of adopting environment-friendly land management measures remain unaddressed. Firstly, from the educational point of view, many of the villagers may not be aware of the availability of such technologies, or do not understand the seriousness and consequences of land degradation and, therefore, are reluctant to practise erosion control and conservation farming. Secondly, from the legal perspective, current land property rights patterns reduce the incentives to use soil conservation technologies. The country's laws do not entitle the farmers with private ownership of the land they cultivate (all lands legally belong to either the government or local community as a whole), and what they are authorised is called "right of use", which gives farmers a limited tenure (usually 30 years) with no legal rights to sell or inherit the land. Under this institutional arrangement, any long-term investment on land conservation or improvements is considered "irrational". As a consequence, soil conservation, as a long term strategy, is not always on the top priority of farmers' land management options. Thirdly, from an economic angle, intensive soil erosion is closely related to farmers' employment options. China's current policy system does not offer rural inhabitants a sound environment for off-farm employment. Job seekers from the remote regions, like those who live in the Loess Plateau areas, are generally much weaker in the labour market in competing with their peers from more developed regions. Thus most of the farmers have to rely on the fragile farmland to make a living. As agriculture extension service is not usually available and input is not often affordable, extensive farming of the erosion-prone land becomes their inevitable choice.

6. Discussion and conclusion

Soil erosion, as one of the most urgent environmental challenges in the Loess Plateau, is not a stand-alone problem. Past effort contributed to understanding the issue from various perspectives but did not generate ideal outcomes. Lack of effective inter-disciplinary cooperation and action, especially the absence of policy studies and reform, made local farmers (the core stakeholders) less likely to consciously and positively engage in combating the environmental degradation. It is apparent that access to all available technologies is the essential condition that makes the conservation practice possible, whilst social and economic factors are the conditions that make it happen.

The current situation on the Plateau calls for careful considerations by the authorities in policy designing. Drawing from previous experiences will help the region achieve environmental stability and economic improvement. It is evident that integrated approaches employing both natural and social aspects enable effective solutions for long-term land conservation, food security and economic development. Interdisciplinary research and corresponding actions, including catchment-scale planning, community participation, ecosystem science and adaptive management, are essential in reversing damages to ecosystems and in promoting regional sustainability. It is also proven that a series of social reforms are needed. Regional development policies should be improved to create alternative industries for off-farm employment in order to offset the pressure of much intensive farming and overuse of natural resources. Legal systems, such as land property rights, need to be adjusted to motivate farmers' far-sighted behaviour in land management. Ecological services provided by environment-friendly farming practices should be integrated in national economic accounting system. With all these measures in place, the success in the study and demonstration sites will undoubtedly scale up to the entire region and promote sustainable development on the Loess Plateau.

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Introducing Chinese rainfed agricultural system to Kenya: a promising strategy to cope with climate change and food security

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Abstract

Arid and semiarid areas comprise 82% and 52% of the total land area in Kenya and China, respectively. However grain yield per unit area and rainwater use efficiency in Kenya are less than 35% and 30% of China, respectively. China and Kenya are also among the countries that are highly suffering from global warming; however China's integrated rainfed agricultural system produced sufficient food and considerable biomass to enhance carbon sequestration. Comparative experiments were carried out with maize crop at Katumani research centre, Kenya, in the long rainy season of 2012, where water harvesting technologies derived from Chinese rainfed systems were used. The treatments tested included maize planted in ridge and furrow system (RFS) with transparent and black plastic film, RFS with mulch applied, RFS without any mulch, and on flat ground. The results showed that there was greater potential of RFS with plastic or grass straw mulching in Kenya than China. Grain yield, rainwater use efficiency and biomass accumulation of maize in Kenya were increased by 100-300% as a result of introducing Chinese rainfed farming techniques. This farming system would provide sufficient food and soil carbon sequestration for Kenya and accordingly act as a strategy to cope with climate change. Our study provides a novel understanding on the role of dryland agriculture in mitigating strategies for climate change and a practical approach for a solution for food security in dry lands worldwide.

Introduction

The effects of climate change on agricultural ecosystem have received considerable attention worldwide (Delgado *et al.* 2012; Parry and Ruttan 1991). Systematic field experiments and observations for agro-ecosystems in the world showed the yields of crops were increased in past decades (Rasmussen *et al.* 1998) and global grain production doubled greatly reducing food shortage (Siddique *et al.* 2001). Global change, because of increased emissions of greenhouse gases, involves global warming (Meehl *et al.* 2012) and fluctuations in rainfall quantity (Cregger *et al.* 2012). This is likely to bring new challenges for agro-ecosystems through direct and indirect effects on cropping systems (Iglesias *et al*. 2012), especially in dryland agro-ecosystems which cover huge areas (globally 54 million km^2 or 40 per cent of the land area is occupied by drylands) (WMO 2005). Consequently the implementation of innovative practices and advanced managements for dryland agro-ecosystems are needed.

From the perspective of sustainability, increased soil carbon sequestration in agro-ecosystems is a critical issue (Srinivasarao *et al.* 2012). The global soil carbon pool (2500Gt) is the biggest C storage in the terrestrial ecosystem and the soil C pool is 3.3 times the size of the atmospheric pool

(760Gt) (Lal 2004). In addition, soil carbon sequestration is a strategy to achieve food security through improvement in soil quality (Lal 2004). Returning higher amounts of crop residue to soil has an increasingly positive effect on soil carbon content (Rasmussen *et al.* 1998). An increase of 1 ton of soil carbon pool in degraded cropland soils may increase crop yield by 20 to 40 kg/ha for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas, thus enhancing food security (Lal 2004). Returning residue to soil rather than removing it since the 1950s has converted many soils from "sources" to "sinks" for atmospheric CO_2 involved in global climate change.

The Loess Plateau of northwest China is characterized by a semiarid monsoon (Liu *et al.* 2009). The agro-ecosystems in this region are rain-fed (Ye and Liu 2012). Scarce and unpredictable precipitation and low water availability are the major factors limiting agricultural productivity (Gan *et al*. 2009; Siddique *et al.* 2001; Turner 2004). Since 1978 the film mulching system has been introduced in China (Zhou *et al*. 2012). Several other innovative methods were applied in Loess Plateau. Nowadays, a new mulching and tillage pattern, ridge-furrow mulching (RFM) system has been widely adopted and has made a significant impact on the regional food and feed security (Li *et al.* 2001). In addition, the RFM system requires low economic input and is extensively adopted by local small household farmers. It is currently recognized as one of the most effective measures to control soil erosion and waste of surface runoff (Kornecki *et al.* 2005), to increase water use efficiency (WUE) as well as to optimize yields (Li *et al*. 2000). The coverage reached 193×10^3 ha in 2008 in Gansu, which occupied about 7% cropland but contributed 20% to the total grain yield in Gansu Province, Northwest of China. Amongst the many benefits of RFM system, the most important is to increase the topsoil temperature and reduce evaporation that helps in increasing environmentally sustainable agricultural production (Gan *et al.* 2009).

Kenya is located at the Horn of Africa in equatorial regions and over 80% lands of Kenya belong to arid and semiarid areas. Kenya is extensively recognized as one of the most sensitive areas to global climate change as is the Loess Plateau of China. Due to inefficient productivity, grain yield per unit area and rainwater use efficiency in Kenya are respectively less than 35% and 30% of those of China. Semiarid Kenya has relatively abundant rainfall and fine sunlight resources. Historically, mean annual rainfall in this area was about 700mm (Kaggwa *et al.* 2011), which is relatively higher when compared to the Loess Plateau, and provides greater potential to develop rainfed farming system. In this area, however, rainfall is highly variable in two growing seasons each year. On the other hand, most of the farmers are poor smallholders. Due to lack of capital and poverty, they have low adoption rate of expensive technical innovations (Mati *et al.* 2011). New technology introduced must be cheap and efficient; otherwise it will be impossible to extend. Local small subsistence farmers are not likely to adopt those farming systems which require high input such as drip irrigation system with long-distance water transportation. Instead, any cheap but efficient farming system will be of great potential to be adopted.

To assess the feasibility and effectiveness of new rainfed farming system in semiarid Kenya, we introduced Chinese RFM technology to Kenya in the long rainy season of 2012. The Loess Plateau of China and semiarid Kenya were compared in rainwater productivity and soil quality. The objectives of this study include: 1) to ascertain if the RFM system is feasible to enhance the field productivity of the agro-ecosystem in semi-arid areas of eastern Kenya and 2) to determine if the system can be beneficial in soil carbon sequestration and in coping with global change in the semi-arid areas of Kenya.

Materials and methods

Description of the study sites

Two separate field experiments were conducted in the typical semi-arid areas of Kenya and the Loess Plateau of northwest China from April to September 2012. Experimental site in Kenya is located at the Agricultural Research Institute (KARI), Katumani (1°35′S, 37°14′E; altitude 1560 m). It has typical rainfed agricultural system, with a mean annual rainfall ranging between 500 and 700 mm and an annual reference crop evaporation of about 1800 mm. Local rainfall is highly variable and mainly occurs in two rainy seasons, each of which receives on average, from 250 mm to 300 mm. Experimental site in China is the Semiarid Rain-harvesting Experimental Station of Yuzhong, Gansu Province in the Loess Plateau (35° 53′N, 104° 04′E, and altitude 1960m) of northwestern China. Local climate is medium-temperature semiarid with a mean annual air temperature of 6.5°C. The mean annual precipitation is 320 mm, of which about 60% falls in the major part of the growing season, between June and September. Rainfall during the experimental period in 2012 was 86.7 mm in Katumani Station and 346.4 mm in Yuzhong Station.

Experimental design and field management

The field experiments at both the sites were comparable. We tested the cheap and efficient farming technology for growing maize in semiarid Kenya, which has already been applied on a large area of semiarid Loess Plateau of China but never used in Kenya. Simultaneously, comparative experiment with same cultivar was conducted in the Loess Plateau. The design of RFM system was according to existing technical standard largely applied in northwest China (see the schematic diagram of RFM system) (Fig. 1A). Four treatments were tested at Katumani as follows: 1) ridge-furrow system mulched with transparent film (TMRF) (polyethylene film with the thickness of 0.008 mm); 2) ridge-furrow system mulched with grass straw (GMRF); 3) ridge-furrow system without any mulching (BRF); and 4) check (CK) system which had flat plot without mulching. The distance between two rows alternated between 60cm and 30cm as control (CK) (Fig. 1B). The large ridge (60cm in width by 10cm in height) was alternated with the small ridge (30cm in width by 15cm in height). In semiarid Loess Plateau, the transparent plastic film

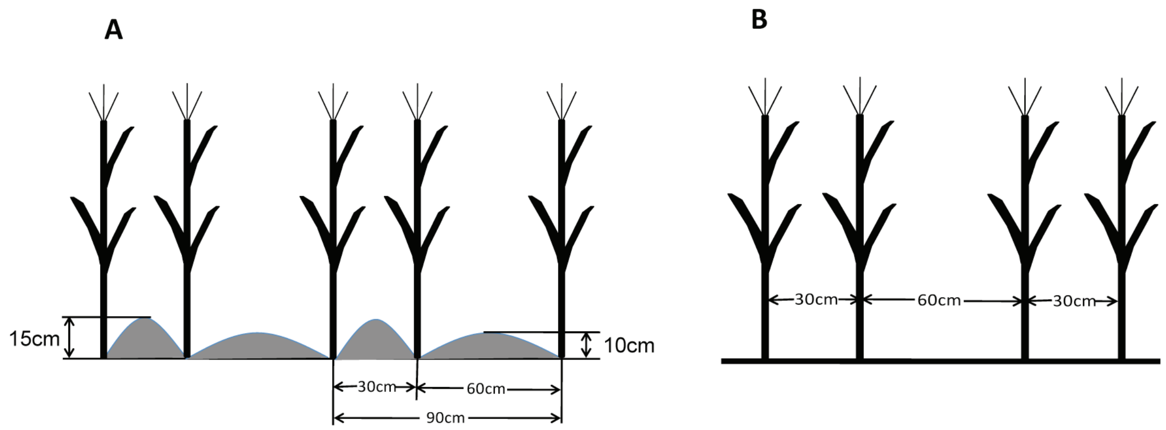

Figure 1: Sketch of ridge-furrow system (A) and the conventional plat planting method (B).

is most commonly used. A large number of experiments done in the past showed that TMRF is the best treatment in the Loess Plateau. Hence the treatments used here were only TMRF and CK.

The maize hybrid *Funong 1* was chosen as experimental material. The ridges were made and covered with plastic film by manually operated machine. The seeds were sown using a hole-sowing machine on 15 May in Katumani Station and 15 April in Yuzhong Station respectively. The harvesting was on 10 September in Katumani and 29 September in Yuzhong. The planting density for both stations was the same (5,000 plants ha^{-1}). Each treatment was replicated thrice in a completely randomized block design and each plot was 5 m long and 4 m wide. The parameters investigated included grain yield, water use efficiency, soil temperature, moisture, soil organic carbon from the two sites.

Sampling and measurements

Soil water content was determined gravimetrically every one week to a depth of 100 cm at 20 cm increments. The soil samples used to measure moisture were cored from a spot in between two plants in the furrows. Topsoil temperature at 10 cm depth was recorded every half-hour during the growing season using automatic temperature recorder (made in USA) buried in the centre between two plants in the furrows. Crop yield and above-ground biomass of each plot was measured. All samples of grain and straw were oven-dried at 105°C for 1 h and at 70°C for a minimum of 72 h. Soil organic carbon (SOC) was determined using an Elmentar Analysensysteme (GmbH VarioEL) at 450°C and the soil bulk density was determined in undisturbed soil cores. The meteorological data for both sites were obtained from the China Meteorological Data Sharing Service System and Kenya Agricultural Research Institute, Katumani Research Centre.

Data statistics and analysis

Water use efficiency (WUE) for each treatment was computed as grain yield divided by evapotranspiration (ET) in the growing season of the crop. The ET was the total of the rainfall during the season and the soil water content (0–200 cm) difference between the beginning and end of the growing season. Since there was no irrigation, infiltration is presumed to be limited for both experimental stations. Water productivity in terms of rainfall and above-ground biomass was calculated by dividing total above-ground biomass (kg ha^{-1}) in the mature crop by total rainfall (m^3 ha^{-1}) during the crop growing season. Leaf area index (LAI) was calculated by dividing total leaf area per plot by the area of the plot. Leaf area was computed by using the formula: leaf length × leaf width × 0.79. The harvest index (HI) was computed by dividing seed yield of each individual plant by total above-ground biomass yield of each plant. Using the SAS package (SAS Institute, 1989) ANOVA was used to conduct analysis of variance. Figures were drawn using the Origin 7.5 software. Comparisons were done with least significant difference (LSD) at the 0.05 probability level. Pearson correlation analysis was performed to check for the presence of the significant relationships among the year to rainfall and temperature parameters.

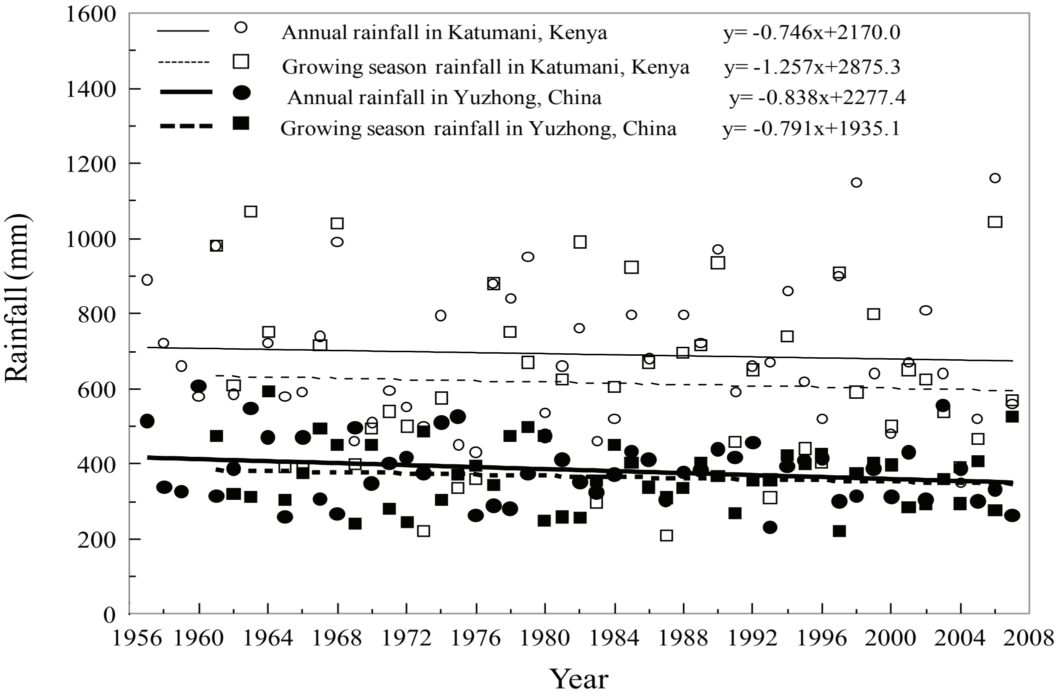

Figure 2: Measured annual rainfall and growing season rainfall from 1957-2007 in the dryland cropping area in Katumani station of East Africa highland and Yuzhong station of Loess Plateau.

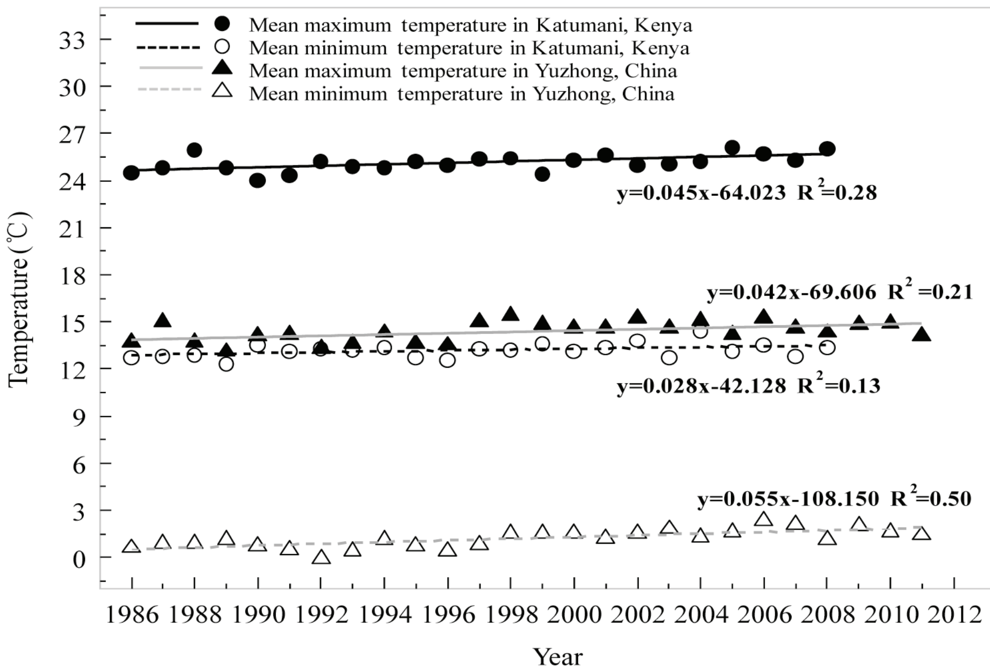

Figure 3: Measured mean maximum/minimum temperature, from 1986-2008 in the dryland cropping area in Katumani station of East Africa highland and from 1986-2008 in Yuzhong station of Loess Plateau.

Results

Climate change scenarios

Long-term (1959-2008) variation in annual rainfall for Katumani Yuzhong was analyzed (Fig. 2). Linear regression analysis indicated that annual rainfall tended to decrease over the past five decades, suggesting that global change led to drier trend in both site. Furthermore, the rainfall within growing season was much lower than the mean annual value for both sites, the decrease in Katumani being higher than in Yuzhong. Both mean annual rainfall and growing season rainfall for Katumani were higher than those of Yuzhong pointing to greater potential for rainfed farming for the former in comparison to the later.

In addition, warming trend was observed at both sites from 1986 to 2012 (Fig. 3). Mean annual air temperature in Katumani was 10.2 °C greater than that of Yuzhong, suggesting that Katumani had better thermal resources for crop production. There was an increase in both mean maximum and minimum air temperatures over last decades. The slopes of the regression lines for mean maximum temperature were 0.045 and 0.042 in Katumani and Yuzhong respectively. The slopes of the mean minimum temperature were 0.028 and 0.055, respectively. For high-latitude Yuzhong, the contribution of minimum temperature variation to mean temperature was greater than that of maximum temperature. On the contrary at low-latitude Katumani, the contribution of maximum temperature variation to mean temperature was greater than that of minimum temperature.

Dynamics of soil moisture

In all treatments, soil water content in 0-40 cm soil layer was low due to low rainfall during the growing season (Fig. 4). Mulching and ridge-furrow treatments significantly increased soil water status. Soil moisture in two mulching treatments (TMRF and GMRF) was significantly greater than in BRF and CK treatments ($P<0.05$). TMRF was more effective in harvesting rainwater and conserving soil water than GMRF. During the early growth period from sowing to tasseling, soil moisture in TMRF treatment was significantly greater ($P<0.05$) than that of GMRF, BRF and CK. With time, soil moisture tended to decrease in all treatments, yet the rate of decrease in soil moisture in TMRF was less than that of other treatments. Soil moisture in GMRF treatment was also significantly higher ($P<0.05$) than in BRF and CK, while no significant difference was found between BRF and CK. In the late growing period, from tasseling to maturity, soil water content in TMRF was still significantly greater ($P<0.05$) than that of other treatments, but no significant differences were observed among GMRF, BRF and CK. On the 70th day after sowing, soil moisture in all treatments decreased to the lowest value (Fig. 4) and that of GMRF, BRF and CK was near the permanent wilting point. Afterwards, soil water status improved with the supplementation of rainfall in late growing period. Results indicated that TMRF was a critical farming technology to improve soil moisture conservation in semiarid Kenya.

Dynamics of soil temperature

Soil temperature of topsoil at 10 cm depth was measured daily. The RFM system significantly enhanced soil temperature during growing season and the extent of increase differed with treatments and growth duration. On the 7th day after sowing, the soil temperature in TMRF was 27.5 °C (i.e.

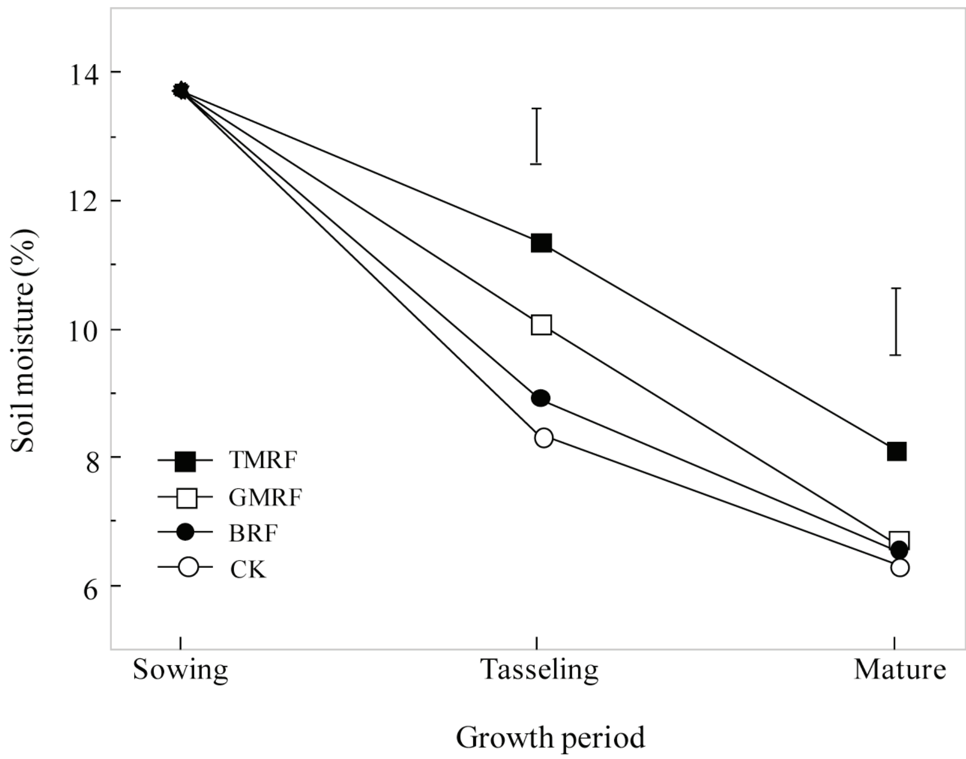

Figure 4: Soil moisture (%) of plough layer (0-60cm) in various treatments during growth season in 2012 in Katumani station. Bars are LSD at P < 0.05.

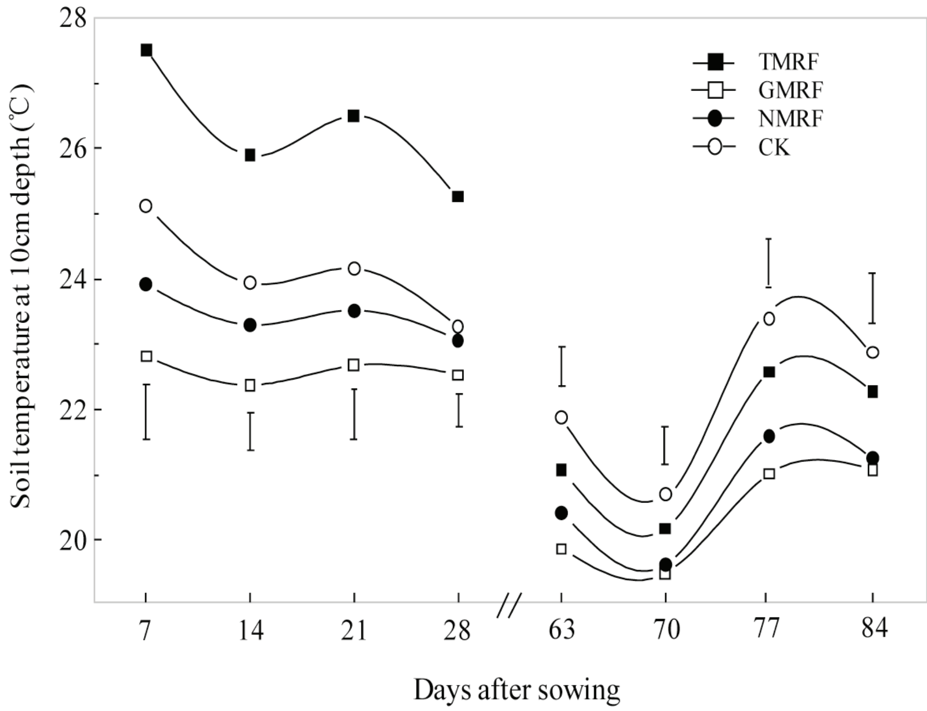

Figure 5: Mean daily soil surface temperature at 10cm Depth in various treatments during the early growing season (7 to 28 days) and late stages of growth (63 to 84 days) in 2012 in Katumani station. Bars are the LSD at P < 0.05.

4.7 °C, 3.6 °C and 2.4 °C higher than that of GMRF, NMRF, and CK, respectively). The similar trend was observed from 7th to 20th day after sowing. At the early stage of crop development (20-70 days after sowing), soil temperatures in TMRF and GMRF were significantly greater than those of BRF and CK. At this stage, vegetative growth experienced a rapid development before the canopy closure (0-70 days after sowing) and accordingly the TMRF and GMRF could increase soil temperature. After canopy closure (almost 70 days after sowing), the TMRF retained a relatively higher temperature and the CK had the lowest. There was no significant difference between GMRF and BRF treatments. This showed that ridge and furrow treatment will play a major role in enhancing soil thermal balance. In general, soil temperature in TMRF treatment was significantly greater than that of other treatments (Fig. 5).

Above-ground biomass and grain yield

Above-ground biomass and grain yield in both sites are shown in Table 1. The RFM system improved the above-ground biomass, grain yield and harvest index at both sites. In Katumani station, the highest above-ground biomass and grain yield were recorded in TMRF. The above-ground biomass and grain yield in GMRF was also significantly ($P < 0.05$) higher than BRF and CK and there was no significant difference between BRF and CK. Compared to CK grain yield increased by 133.2% in TMRF, 75% in GMRF and 25.5% in BRF. The highest harvest index (0.314) was also found in TMRF. In contrast to Yuzhong station, above-ground biomass, grain yield and harvest index in TMRF and CK were lower in Katumani station, perhaps due to more limited rainfall in the growing season, although the yield increase in TMRF of Katumani station (133.2%) was clearly higher than that of Yuzhong station (53.8%).

Table 1: Above-ground biomass, grain yield and harvest index in various treatments in 2012 in Katumani station and Yuzhong station

Treatment	Katumani station, East Africa Highland				Yuzhong station, Loess Plateau			
	Above-ground biomass (kg ha^{-1})	grain yield (kg ha^{-1})	Harvest index	Increase in yield (%)	Above-ground biomass (kg ha^{-1})	grain yield (kg ha^{-1})	Harvest index	Increase in yield (%)
TMRF	15163.7 Aa	6852.8 Aa	0.314 Aa	133.2	42188.9 Ab	12124.4 Ab	0.485Ab	53.8
SMRF	11960.4 B	5142.4 B	0.262 CD	75.0	—	—	—	—
NMRF	9643.1 C	3688.3 C	0.272 BC	25.5	—	—	—	—
CK	8685.7 Ca	2938.2 Da	0.234 Da	—	18733.8 Bb	7881.5 Bb	0.420 Bb	—

Means within columns followed by different letters (A, B, C and D) are significantly different at $P < 0.05$. Means within rows followed by different letters (a and b) are significantly different between same parameters of both stations at $P < 0.05$.

Water use efficiency (WUE) and water productivity (WP)

The WUE and WP data are presented in Table 2. At Katumani station, most stages of maize development were limited by moisture deficit because the crop grew during the dry season. Only 86.7 mm rainfall was available during the whole growing season. While at Yuzhong station maize found a growing season with relatively abundant rainfall (346.4 mm). For both stations, the highest WUEs were recorded in TMRF. In Katumani, WUEs were 39.6, 26.5, and 23.9 kg ha^{-1}

Table 2: ET, water use efficiency (WUE) and water productivity (WP) in various treatments in 2012 in Katumani station and Yuzhong station

Treatment	Katumani station, East Africa Highland							Yuzhong station, Loess Plateau						
	Rainfall (mm)	SWC (mm)	ET (mm)	WUE (kg ha^{-1} mm^{-1})	Increase in WUE (%)	WP (kg m^{-3})	Increase in WP (%)	Rainfall (mm)	SWC (mm)	ET (mm)	WUE (kg ha^{-1} mm^{-1})	Increase in WUE (%)	WP (kg m^{-3})	Increase in WP (%)
TMRF	86.7	86.3	173.0	39.6	88.6	1.7	70	346.4	-27.2	319.2	38.0	61.1	1.2	125.2
SMRF	86.7	107.6	194. 3	26.5	26.2	1.4	40	—	—	—		—	—	—
NMRF	86.7	67.9	154.6	23.9	13.8	1.1	10	—	—	—		—	—	—
CK	86.7	52.9	139.6	21.0	—	1.0	—	346.4	-12.2	334.2	23.6	—	0.5	—

Rainfall: the total rainfall during the maize growing season, SWC: the difference in soil water content of the 0–100 cm layer between that at the beginning and at the end of the experimental period, ET: evapotranspiration, WUE: water use efficiency based on.

Table 3: Change of soil organic carbon from sowing to harvesting and residual root in various treatments in 2012 in Katumani station and Yuzhong station, respectively

Treatment	Soil depth (cm)	Katumani station, East Africa Highland				Yuzhong station, Loess Plateau			
		SOC before sowing (g kg^{-1})	SOC after harvesting (g kg^{-1})	Decrease in SOC (g kg^{-1})	Residual root biomass (g plant^{-1})	SOC before sowing (g kg^{-1})	SOC after harvesting (g kg^{-1})	Decrease in SOC (g kg^{-1})	Residual root biomass (g plant^{-1})
TMRF	0-20	13.1	11.5 A	4.1	13.59 Aa	7.6	6.9 A	3.8	12.25 Ab
	20-40	11.6	9.7 A			7.1	5.0 A		
	40-60	7.9	7.3 A			7.0	6.0 A		
SMRF	0-20	13.1	11.5 A	3.5	10.62 B	—	—	—	—
	20-40	11.6	9.5 A						
	40-60	7.9	8.1 B						
NMRF	0-20	13.1	11.8 B	3.0	9.34 C	—	—	—	—
	20-40	11.6	9.8 B						
	40-60	7.9	8.0 B						
CK	0-20	13.1	12.4 C	2.3	8.97 Da	7.6	7.1 B	0.5	8.25 Bb
	20-40	11.6	10.6 C			7.1	6.5 B		
	40-60	7.9	7.3 A			7.0	7.6 B		

Means within columns followed by different letters (A, B and C) are significantly different at $P < 0.05$. Means within rows followed by different letters (a, b) are significantly different between same parameters of both stations at $P < 0.05$.

mm^{-1} in TMRF, GMRF and BRF, respectively, remarkably higher than that in CK (21 kg ha^{-1} mm^{-1}). Compared to Yuzhong station, WUE and its increase in TMRF were clearly higher than in Katumani. At both stations, WP was highest in the TMRF treatment. WP of the mulched plots increased by 10%-70% in comparison to CK. At Yuzhong station WP was lower than in Katumani.

Soil organic carbon (SOC) and root residue

The change of SOC and residual root biomass in the upper 60cm layer during the experimental period is presented in Table 3. Before sowing, the SOC reduced with depth in both experimental stations.

At Katumani station, after harvesting of maize, SOC in two mulched plots was significantly ($P < 0.05$) lower than in the no-mulched plot and CK in the 0-20cm soil depth and the same tendency was recorded in the 20-40 cm depth. No significant difference was found between TMRF and CK in the 40-60 cm soil depth. TMRF treatment led to more loss in SOC (4.1 g kg^{-1}) than other treatments (i.e. 3.5 g kg^{-1} in SMRF, 3.0 g kg^{-1} in NMRF and 2.3 g kg^{-1} in CK) between the periods from sowing to harvesting. However, the residual root biomass in TMRF was 13.59 g plant^{-1}, significantly ($P < 0.05$) higher than in other three treatments.

In contrast to Katumani station, SOC before sowing and after harvesting in corresponding soil depth in TMRF and CK was lower in Yuzhong station. The lower reduction of SOC in 0-60cm depth in TMRF was also recorded in Yuzhong station (3.8 g kg^{-1}) compared to Katumani station (4.1 g kg^{-1}). However, the SOC change in the 0-60cm depth in CK tended to be higher in Yuzhong station. The residual root biomass was significantly ($P < 0.05$) higher in TMRF than CK in Yuzhong station, but significantly ($P < 0.05$) lower than Katumani station in the corresponding treatments.

Discussion

Ridge-furrow mulching system under climate change

The long-term historical data over past several decades support the view that regional climate in the dryland of Loess Plateau and semi-arid areas of eastern Kenya is moving towards more dry and hot conditions (Fig. 2.3). Compared to the Loess Plateau, the condition of water and heat resources in the semi-arid areas of eastern Kenya seem less severe due to the influence of water masses such as Western Pacific and Lake Victoria. But the high, evaporative demand and the high loss of water due to surface runoff severely limit soil water availability and threaten agricultural sustainability in this area (Gicheru *et al.* 2004). This issue has become more serious as result of global climate change. In the Loess Plateau, to tackle the same problem, ridge-furrow mulching system, as a micro-rainwater harvesting practice, has been developed to increase soil water availability in rainfed farming systems that are reliant on precipitation. The main purpose of ridge-furrow system is to reduce evaporation and water erosion (Kornecki *et al.* 2005), improve soil water-temperature -combination (Liu *et al.* 2009; Zhou *et al.* 2012), and suppress weeds (Hegazi 2000; Johnson and Fennimore 2005). In addition , the ridge-furrow mulching system has been shown to be most effective in areas where rainfall is sudden, heavy and unpredictable, and surface evaporation is large (Huang *et al.* 2006; Yao and Yin 1999). The annual mean rainfall and growing season rainfall in Katumani was around 700mm and 400mm, respectively, but annual reference crop evaporation was about 1800mm (Mungai *et al.* 2000). Therefore, dryland agricultural ecosystem in semi-arid areas, represented by Katumani station, has more favorable natural conditions to develop ridge-furrow mulching system under climate change.

Productivity and water use efficiency

The above-ground biomass and grain yield productivity in the mulching treatments, especially in transparent film mulching plot, was higher than that in the unmulched and control plot. This was probably because ridge-furrow mulching system increased the availability of soil water and modulated soil temperature in different developmental stages and finally led to synergy of soil water and temperature in affecting maize development during the whole growth season. Firstly, the main positive effect of mulching is to reduce evaporation and water erosion (Kertesz and Loczy 1996), and augmenting the infiltration of rainwater into the soil (Ramakrishna *et al.* 2006). It is expected that the infiltration and soil water retention could be improved remarkably (Ghosh *et al.* 2006). Secondly, the design of alternating ridges and furrows create rainfall harvesting zones and water use areas. The ridges are able to catch and reallocate rainwater into furrows and minimize surface water runoff, thereby increasing the water flow to the roots of maize planted in the furrow. In Katumani station, the soil water content in 0-40cm soil layer in TMRF was significantly higher than other treatments throughout the maize developmental stages and also in SMRF it was significantly higher than that in the unmulched plots in the intermediate periods of maize growth. Thirdly, the main constraint on crop production in the semi-arid areas of eastern Kenya is not temperature while higher soil temperature combined with water deficit during the dry spell seriously affects the crop development, especially for the reproductive success. The technology introduced can ease the adverse effects. In our experiment, the mulched plot with film usually warmed up more quickly than the unmulched treatments at the seedling stage of maize development (Fig. 5). This is because maize canopy is small, allowing most of the soil surface mulched by the plastic film to receive solar energy causing the topsoil to warm up at this stage.

The seedling stage of maize development in the semi-arid areas of eastern Kenya are usually timed to occur in the rainy season, therefore the combination of adequate soil moisture and relatively higher temperature can facilitate the successful establishment and rapid growth of the seedlings. However, as the maize season progresses, the soil temperature of film mulched treatment was lower than the conventional flat planting treatment at the beginning of reproductive stages (63 days later after sowing) (Fig. 5). The primary cause is that the treatment with film covering results in larger maize canopy deterring more sunshine reaching the soil surface. From the tasseling to maturity, maize growth in Katumani is exposed to dry season, rainfall deficit. High temperatures can cause maize seed abortion and decrease in production. The cooling effect at reproductive stage under ridge-furrow mulching system can alleviate these problems to some extent. Overall, the improvement of soil water-temperature regime with the ridge-furrow mulching system, especially in film mulched treatment, led to the increased yield of maize above-ground mass and grain.

Considering the limitation of rainfall in the dryland agriculture ecosystem in the Loess Plateau and semi-arid areas of eastern Kenya, water use efficiency is extremely important for productivity of arable land. The magnitude of the effect of ridge-furrow mulching system on WUE is often greater when growing-season precipitation is lower than normal, as mulching and ridges-furrows design help conserve and collect limited rainwater (Ren *et al.* 2009). Our experiment demonstrated improved WUE in Katumani which was significantly higher than Yuzhong due to lower rainfall of the former. On the other hand, crops grown in ridge-furrow mulching system can expose their upper roots to drying topsoil. When drought occurs, the upper roots can respond by sending chemical signals to the shoot without any detectable change in shoot water relations (Blackman and Davies 1985; Blum and Johnson 1993; Croker *et al.* 1998). This root-induced signal helps close leaf stomata and retard growth, thereby reduce water loss through reducing crop transpiration, without preventing photosynthesis, resulting in higher WUE (Wang *et al.* 2005). Therefore, the ridge-furrow mulching system can increase crop water use efficiency not only through effective rainfall collection and storage but also by crop physiological regulation using the root–shoot communication theory.

Soil carbon pool and aboveground carbon fixation

Agricultural lands occupy about 37% of the earth's land surface (FAOSTAT 2005). The annual emission of green house gases (GHGs) from agricultural ecosystems is expected to increase in coming decades due to escalating food demands. Agricultural GHG fluxes are complex and heterogeneous but the emerging technologies and effective management of agricultural ecosystem also offer possibilities for mitigation. Increasing soil carbon sink and above-ground carbon fixation as main solutions for agricultural sustainability, has received increasing interest by research scientists and policy makers in the recent decades. Combining appropriate technologies with the increasing adoption of conservation tillage practices and crop productivity, could result in decreasing CO_2 emissions from soils (Smith *et al.* 2007). Our results showed that the above-ground production and water use efficiency were remarkably higher in mulched plots than the check treatment. The soil organic carbon losses in grass mulched plot was slightly higher than control, but the significant increase in residual root biomass in GMRF treatment can be expected to increase the potential for soil carbon pool.

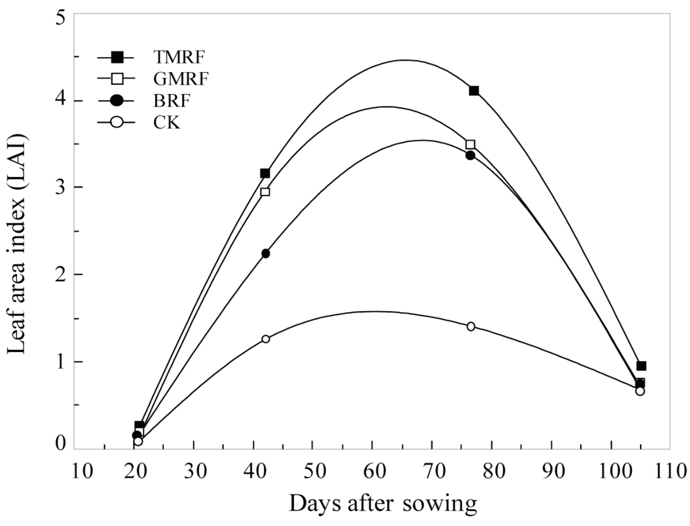

Figure 6: Leaf area index change of various treatments during growth season in 2012 in Katumani station.

The vegetation cover plays a key role in determining the amount of CO_2 in the atmosphere coupled with global carbon fixation, related global water and nutrient cycles and heat exchange (Peñuelas and Filella 2001). The longer presence of green cover generates a cooling that mitigates warming by sequestering more CO_2 (Peñuelas *et al.* 2009). Leaf area index (LAI), as an indictor of degree of green cover, in ridge-furrow mulching systems (TMRF and GMRF) was nearly four times higher than in the conventional flat planting in Katumani station (Fig. 6). The time span of green cover in TMRF and GMRF was also longer than in other treatments. The higher LAI and longer presence of green cover allows crop to absorb and utilize more CO_2 from the atmosphere and may lead to long-term increases in carbon storage and changes in vegetation cover which in turn may affect the climate system. The ridge-furrow mulching system can be recommended as one effective practice for GHG mitigation in agricultural ecosystem

Using one growth season data from two experimental stations, our results merely present possible opportunities for the improvement of soil carbon sink and dryland agricultural sustainability in ridge-furrow mulching system. The effect of novel farming practices on soil carbon pool and the process of carbon cycle would require a long-term exploration in order to produce credible conclusions.

Conclusions

In the semi-arid areas of eastern Kenya, the benefits of ridge-furrow mulching system to maize crop appeared to be enormous, which can contribute to regional food safety by increasing crop productivity and grain yield and also increase the sustainability of dryland agroecosystem through increase in soil carbon pool and aboveground carbon fixation. In addition, soil erosion and surface water runoff can be mitigated due to the efficacy of film mulching. The shortage of livestock feed can also be reduced by transferring the increased crop straw from the agro-ecosystem to animal husbandry. However, the successful introduction of novel farming practices needs to go through a long process from the stage of experimentation and demonstration to extension. Long-term observation and research would however be needed to fully assess the effects of newly introduced technology.

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Advance farming in the desert - the Israeli experience

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Abstract

Desert constitutes 60% of the total area in Israel. The annual precipitation is 100-200 mm and evaporation reaches 2500 mm. Traditional desert agriculture of growing rainfed wheat and grazing sheep, goat and camels is common. Despite the harsh climate conditions, advance agriculture is concentrated in locations where water resources exist. Mild climate season of winter (October-April) is used for growing vegetables, flowers, herbs and fruits, mostly for export to European countries. The key is sustainable management of the local natural resources. The local research and development system is generating adequate knowledge and technologies. The most important factor is developing water resources, and using them efficiently by drip system and protected agriculture (greenhouses and plastic tunnels). The unfit desert soil is substituted by sand and artificial growing media. For gaining market, botanical species of special flower and vegetable crops, avocado, pitaya, jojoba are introduced. Controlled drip irrigation and drainage helps to solve salinity problems. Integrated Pest Management is used to overcome plant protection issues. Advanced raising of milking cows was developed by using heat stress reduction methods. Raising fish in protected ponds and ostriches were adapted to desert conditions. On the southern Judean hills where precipitation is 250 mm, soil conservation work and rain water harvesting has permitted afforestation, which is changing the desert scenery. Farmers, extension agents and research scientists have all contributed to these developments.

Introduction

Agricultural production and desert conditions are usually considered to be incompatible. Since the desert is an area with adverse climate and soil conditions, it is unattractive for modern agriculture, even though it also has specific characteristics which could be useful for agricultural development and production. It is necessary to identify the advantages and disadvantages of each of these characteristics and existing natural resources before deciding on large-scale development program. For developing modern agriculture, it is necessary to generate know-how and specific technologies needed for the utilization of desert resources. This can only be done by intensive local research under desert conditions.

The success or failure of desert development depends on the human factor. Exclusively dedicated human resource is needed to settle in desert and be able to use scientific and technologically advanced cultivation methods and apply environment control needed for successful performance under adverse desert conditions. This approach requires abundant economic resources. Applying state-of-the- art technologies in greenhouses, makes it possible to control almost all factors influencing plant growth, such as temperature, humidity, radiation, protection from wind, growth media and plant nutrients.

Israel is a small country in the Middle East with a total land area of about 26,000 km^2. Sixty percent of its territory is desert, with rainfall not exceeding 200 mm/year and limited to the five winter months (November to the end of March), which is the only rainy season of the year. Only 7% of the total population of Israel lives in this area. However, the Israeli desert is not homogenous. It includes the Arava Valley extending from the south of the Dead Sea to the northern part of the Red Sea, and which is part of the Afro-Asian Rift Valley. Part of it is below sea level. Dates, mangos, vegetables, flowers and milk are produced in this valley.

Another part of the desert is the central Negev high plateau of 600 m.a.s.l. This area produces bulbs of flowers such as irises, narcissus and gladioli, as well as olives, grapes, melons and vegetables grown in open fields and in greenhouses. Also Tilapia fish are raised in open ponds and in greenhouses with thermal saline water. The northern Negev desert is flat and hilly, covered by loess soils on which rainfed and irrigated wheat, vegetables, flowers, forage, apple, apricot and citrus (mainly lemons) are produced. The north western Negev desert, near the Mediterranean Sea predominantly consists of sand dunes. These dunes can be easily flattened and cultivated. By using drip irrigation integrated with fertilizer application, Israel's most outstanding agriculture is practiced on these once desolate sand dunes, at present citrus, avocado, mango, vegetables and flowers are grown.

The Israeli Negev desert is characterized by wastelands, low population density, a large number of sunny days with high temperature and radiation levels and scarcity of water. Usually, the few existing limited sweet water resources are only found in oasis. However, like in most deserts of the world, deep saline water aquifers are found that may be utilized when applying specific technological methods. Extreme climatic conditions such as strong winds, sand storms and extreme temperatures frequently occur. One of the characteristics of the desert specific Loess soils is development of superficial crust resulting in low water infiltration rate. The rapid sealing of the surface layer once the soil becomes wet causes immediate water run-off in the form of streams even after a short rainfall. The run-off can be harvested and directed into the fields or reservoirs for later use.

Methodology

This article is based on the approach of sustainable Agriculture. Under these methods, the regional natural resources are examined in order to take advantages of agricultural production. Natural resources as soil, water, crops, animal husbandry, climate and human resource, are investigated in order to reveal their advantages under the local desert circumstances. Regional agricultural research and development (R&D), is being applied in the Negev region and contributes mostly to solve agricultural production problems and introducing adequate innovations. This R&D system is composed of the cooperation of farmer's representatives, local agricultural researchers; extension services agents and representatives of regional authorities. A local R&D committee is in charge to identify the problems and prepare a short and long term local research and extension programs. The same committee monitors the procedures and is in charge of the application practical results. In this article, we present the local natural resources characteristics and after adaptation, their values, which contribute to turn desert into advanced agriculture area.

"Desert Agriculture" and "Modern Agriculture In The Desert"

As early as almost 3000 years ago, an ancient agricultural system known as the Nabatean Agriculture was successfully practiced in the desert. This system is based on water harvesting from nearby bare hill slopes. The run-off water, directed to, and accumulated in cultivated plots located at lower levels, contributed to increase soil moisture. Various vegetables and fruits like olives, almonds, figs and others were successfully grown under this system. This system mainly fits small-scale subsistence farming and is not applicable for more advanced agricultural systems. However, the system has high potential for adoption in the Sahel region of Africa or in other desert areas in Africa, Asia and Latin America. Under this system, Eucalyptus trees can be grown for fire wood, Leucaena trees for fodder for goat and sheep and olive trees for oil production for human consumption.

Another type of traditional agriculture, practiced in the hilly Loess-soil area, where rain-fed wheat cultivation take place during the rainy winter season. Precipitation in this desert area is around 200 mm /year. This amount of rainfall can produce 2 t/h of wheat grain. During summer, sheep and goat herds graze on the wheat stubbles. This is the type of agriculture characteristically practiced by the nomad population of the desert, the Bedouins.

Under the new reality and habits of Israel, modern agriculture is developing and has established itself in the desert. This advanced agriculture can be named "Modern Agriculture in the Desert".

Water

Modern agriculture in the desert is firstly based on the availability of water for irrigation. We are distinguishing between external and local water resources. External water resources are transported by the "National Water Carrier" over a distance of more than 300 km from the Sea of Galilee in the north of the country. Another external resource is the recycled sewage water from the central urban area of Tel Aviv and its satellites cities with a total population of 1.4 million located 80 to 100 km to the north of the target area. After secondary biological treatment, the sewage water undergoes further treatment. It is filtered through sand dunes down to a depth of 80 m where it is stored for a prolonged period of time. After reaching a very high quality almost comparable to potable water standard, the water is pumped into the distribution system to be transferred south to the desert. These two water resources from the north are either immediately used by the agricultural sector in the south or stored in very big reservoirs in the target area, some of which may contain up to 1.5 million m^3 of water.

One of the local water resources is the saline water stored in 1000m deep aquifers. Water is pumped from 700m deep artesian wells. Salinity ranges from 1000 to 2500 mg Cl/L, and the temperature of the water is about 40^o C. The successful use of this saline water requires specific technology.

An Israeli innovation of the early seventies of the last century, the drip irrigation method, makes it possible to use saline water for crop irrigation. Using this method, the relatively long and frequent irrigation applications at a very low water discharge rate, provide a permanent leaching of salts from the root zone. Compared with other irrigation systems, the salt accumulates around the root system which itself remains with relatively low salt concentration. Next season, before starting a new crop in the fields where saline water was used for irrigation, it is necessary to have fresh water for one time flushing and leaching of the accumulated salts to a depth of 1.2 m below the root zone.

Research carried out in recent years identified a long list of crops which are tolerant or resistant to saline water. Among others, they include asparagus, broccoli, beet-root, celery, cabbage, tomato, melon, lettuce, Bermuda grass, Rhodes grass, wheat, sorghum, sugar-beet, cotton, dates, olive and grapes. These crops provide economic yields under a saline water irrigation regime. In some crops, such as tomatoes, the use of saline water leads to a stress response of increased concentration of sugar in fruits yielding"Sweet desert Tomato". In vineyards, the grapes attain a high level of dry matter resulting in the production of high quality wine. Saline water for irrigating olives also improves oil quality.

By using a special sealed pipe system installed near the plants, the thermal water pumped from the well is used for raising the air temperature in the greenhouse during cold nights. After cooling, the same water is reused for irrigation.The thermal water can also be used for the cultivation of tilapia fish raised in fish ponds protected by greenhouses.

Introduction of new plant species

Most of the commercial crops produced by Israel's modern agriculture were developed from species introduced from other parts of the world. As in other agricultural fields, research is continuously searching for new species to be adapted to our desert conditions. In the last years, new crops such Jojoba, Opuntia and Pitaya, were commercially introduced from Mexico on a large scale. The introduction process includes various phases like quarantine, and observations in the demonstration plots, and semi-commercial and commercial plots.

Harnessing climatic variations

The desert area of the Arava valley, part of which is below sea level, is known for its warm temperatures and mild climate during the winter season. Precipitation in the valley is low and erratic, usually not exceeding 100mm/year and relative air humidity is also low. During winter, when it is cold and rainy in the north of the country, it is the best time for producing off-season vegetables, flowers and herbs in the Arava valley. These products obtain the highest prices in the market and are mainly destined for export. The limiting climate factors to be dealt with are wind and hail storms, and sometimes extreme temperatures. Growing crops under protection in greenhouses is the best solution to this set of problems. The agriculture growing season in this area lasts from September to May.

Growth medium

The growing medium in the greenhouses usually consists of sand brought from a local sand dune resource. Other growing media consist of mixtures of sand, compost, rock wool, peat, vermiculite, etc., used as detached media. Irrigation, integrated with fertilizer application, is fully computer controlled. The amounts of water and fertilizers to be applied as well as irrigation frequency are determined by field tests for meeting water and nutrient demands. Special sensors are installed in the plots and used for monitoring soil moisture content and controlling irrigation. In the sandy desert area near the Mediterranean coast, a very advanced agricultural system of citrus, avocado, mango, flowers and vegetables has been introduced. The sand dunes are leveled and cultivated.

Based on the drip irrigation method, high quality recycled sewage water is used for irrigation. The climate in this area is usually mild and the proximity to the sea prevents the frost hazards.

Control of other factors

Under greenhouse conditions, air temperature, humidity, radiation and wind streams can be automatically controlled. Insect-proof nets prevent the penetration of the insect pests that would otherwise transmit virus diseases and in addition to causing physical damage to the plants. The plastic sheets used for covering the greenhouse possess Ultra Violet or Infra Red (IR) characteristics, thereby achieving additional advantages. The greenhouse atmosphere enriched by CO_2, induced in early morning hours, improves photosynthesis, resulting in higher yields.

Plant protection

Pests and diseases, including nematodes and mites, may inflict heavy damage to the crops and indeed are the most serious limiting factor. Virus diseases, transmitted by vectors such as aphids, mites and white-fly, are capable of completely destroying a crop. The existence of the Mediterranean fruit fly, limits the export of fresh produce to the U.S.A. and Japan. As already mentioned, the protection of greenhouses by insect-proof netting and IR plastics is very useful for controlling insects and strongly diminishing the spread of virus diseases. A specific plant protection project running in the Arava valley aims at controlling pest and disease damages. The project is based on isolating the valley from other agricultural areas and isolating the agricultural plots in the valley itself from each other. The principles of the project are:

- Cultivating in autumn, winter and spring and maintaining zero-cropping during mid summer.
- Removing all crop residues and trash immediately after harvesting.
- Monitoring and applying control treatments based on threshold values.
- Introducing beneficial insects for biological insect control.
- Using environmental friendly, biologically un-harmful pesticides.
- Introducing sterile males for controlling the Mediterranean fruit fly.
- Using soil fumigant treatment for soil disinfection. This method however was replaced by solarization. Solarization is a soil disinfecting method, whereby the soil bed is covered during mid summer with plastic sheets for a period of one month. The plastic cover traps sun radiation and increases soil temperatures to more than 50^{o} C over a prolonged period of time, thereby achieving the desired soil disinfection effect.

The project, which has already run for 15 years, succeeded to reduce drastically pest and diseases damages, achieved the eradication of the Mediterranean fruit fly in the whole zone, and resulted in permission for exporting agricultural produce to the U.S.A.

Reforestation

The northern desert area includes the southern part of the Judean Hills. In this area, precipitation amounts to 250 mm/year. In the past the hills were completely eroded. By using appropriate soil conservation methods like terracing, fencing with stones and bushes, rainwater is harvested and soil moisture is increased. Species such as *Eucalyptus occidentalis*, *E. stricklandii*, *E. sarangetii*, *Prosopis alba*, P. Juliflora, *P. nigra, Accacia salicina, A. Raddiana, Tamarix, aphylla, Ceratonia siliqua, Pistacia palestina, Pinus halepensis*, and *Pakinsonia aculeata*, are planted in the area and are slowly turning into forests which are completely changing the landscape.

Raising Tilapia fish, ostrich and dairy cattle in the desert

Tilapia fish

The existing deep aquifer in the desert is saline and thermal (40^{o}C). Tilapia easily adapts to this type of water. The optimum temperature for harvesting commercially profitable fish (400g) is 30^{o} C. Under these conditions, the life cycle is short, making it possible to obtain two cycles per year, compared with only one cycle for fish raised at normal water temperatures. Fish raising in ponds located in greenhouses with a forced oxygen environment has the capacity of yielding 15 ton per 1000 m^2. This is a very capital intensive but profitable agriculture.

Ostrich

Ostriches are well adapted to desert conditions and can survive on eroded land of very limited alternative use. They efficiently utilize the scarce natural vegetation produced on the pastureland, but also receive some supplementary feed from other sources. The commercial ostrich products are meat, eggs for ornamental purpose, skin for the leather industry and live animals sold for reproduction purposes. All in all, this is a very profitable agricultural enterprise.

Dairy cattle raised under heat stress conditions

Under heat stress, cattle waste energy for body cooling instead of producing milk; consequently the milk production decreases. Technological innovations were introduced for overcoming heat stress problems. These include: 1) High and well aerated structures; 2) High-potential ventilators; 3) Sprinklers for spreading water droplets; 4) Frequent wetting of the cattle; and 5) Continuous supply of cool drinking water. All these means help reducing the temperature in the cattle shed and diminish heat stress. Under such circumstances, milk production in the hot desert zones can be increased.

The human factor

Among all factors and resources influencing agricultural development in the desert, the human factor is the most important one. The farmer who nowadays settles in the desert, is usually of a very dedicated, but also strongly economically oriented type, who attempts to exploit the advantages (while overcoming the disadvantages) of the desert environment and by developing and applying relevant knowledge and technologies needed for this purpose.

Under the prevailing Israeli circumstances, the Regional Agricultural Research and Development (R&D) system has proved to be very effective. The system is based on regional cooperation, between farmers, researchers, extension workers and local regional authorities. Within the framework of such cooperation, the objectives, working plans and allocation of economic resources, are approved and implemented. The aim of this R&D system is to produce the most relevant, immediately needed solutions and practical knowledge and technologies to be used by the farmers for sophisticated and modern agricultural production.

The development of agriculture in the desert requires relatively high capital investments and additional capital for purchasing sophisticated production inputs. The cost of a 1,000 m^2 large greenhouse alone is around 100,000 US dollars. Such high investments are justified due to the intensive, sophisticated and profitable farming developed as the result of the cooperative management and research efforts of all participating parties.

Farming settlements in the desert require a well developed regional infrastructure, resulting from physical and social regional planning and development. This infrastructure includes, among others, access roads, communication systems, access to production inputs, credit and banking services, and supporting systems for grading, packing and cool-storage of produce. Supporting technological systems and agricultural extension and research services are also essential as well as advanced leadership.

The settler in the desert needs living conditions that allow him to overcome the harsh climatic conditions. Nowadays, this can be achieved by technological innovations in desert architecture, air conditioning and other related fields. Number of impressive innovations have been recently achieved. All in all, if intelligently managed by dedicated manpower, the desert has a very high potential for human settlement and food production.

Conclusion

The Negev desert area of the south of Israel is part of the Sahara desert which extends on all North Africa, Sinai Peninsula and the southern Israeli Negev. The moderate climatic condition in the winter season is the main advantage of the Negev desert area. In open fields and in various types of plastics greenhouses, vegetable, flowers and fruits are grown in winter season and exported to Europe to a high purchase consumer's market. As a result, a very efficient profitable agriculture is created. The Regional Agricultural Research and Development (R&D) system is unique and very efficient in providing practical solutions and introducing innovations to farmers. Efficient use of the saline marginal water resource by using the drip irrigation system, developed in1970 in this region by the local R&D system, has permitted growing high value crops. The local R&D system has also succeeded in overcoming the barrier of desert marginal soils, by introducing the efficient artificial growing media and protected agriculture in plastics greenhouses, to overcome extreme climate events. Despite the hot summer condition, a very efficient dairy system has been developed by the local R&D system by reducing the heat stress in cattle. The local human resource is the key factor of success. Most of the farmers have academic degrees and idealistic motivation. The government policy is to develop an advanced regional infra-structure and support mechanism for regional development. The combination of all these factors is enabling the regional development of desert area through a very advanced rentable agriculture giving high income and high standard of living. This example can serve other desert areas in the world.

Soil microbial attributes along a cropland degradation gradient in Horqin sandy land, northern China

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Abstract

To evaluate the impacts of land degradation on soil microbial attributes in sandy cropland, we examined soil microbial biomass and microbiological activities in a typical agro-pastoral transitional zone in Naiman County of northern China. Lightly degraded cropland (LDC), moderately degraded cropland (MDC) and heavily degraded cropland (HDC)) were chosen according to the magnitude of sand invasion. Both microbial biomass and microbiological activities (quantified as microbial abundance and enzyme activities) decreased significantly as degradation level increased from LDC to MDC and HDC. In addition, correlations between soil microbial biomass carbon and microbiological activities were significant and positive. Further analysis of this relationship identified three key microbiological factors influencing the level of soil microbial biomass carbon. Activity of the enzyme Cellobiohydrolase, and the abundance of *Azotobacter* and *Actinomycete*, were significantly related to soil microbial biomass carbon (stepwise regression: *Microbial biomass carbon = -147.944 + 5.451*Cellobiohydrolase + 2.090*Azotobacter - 0.053*Actinomycete* ($R^2=0.971$, $F=122.941$, $P<0.001$). Thus in Horqin sandy land, cropland degradation reduces not only the productivity and yield, but also the soil microbial attributes.

Introduction

Land degradation in drylands, also called desertification, was defined by the UNCCD (1994) as the loss of biological productivity and complexity of terrestrial ecosystems. Desertification has affected the world for centuries and is a vital societal concern because of its impacts on human well-being (food security, economics, sustainability, etc.) and environmental quality (dust storms, trace gas emissions to the atmosphere, soil erosion, etc.) (Vitousek *et al.* 1997). Cropland degradation is a natural process that involves soil erosion and sedimentation (Reynolds *et al*. 2007). However, it is accelerated by intensive cultivation and results in yield reduction and decline of soil quality (Sonnleitner *et al.* 2003). Wind erosion and sand accumulation are recognized as the primary forms of cropland desertification in the arid and semiarid regions of Inner Mongolia (Zhao *et al.* 2006). Up to now, most of the research on cropland degradation focused on wind erosion processes and the effects of wind erosion on soil physicochemical properties and soil potential productivity (Lowery *et al.* 1995; Lopez *et al.* 1998; Gomes *et al.* 2003; Li *et al.* 2004; Zhao *et al.* 2007). The role of sand accumulation in cropland soil degradation has received less attention. Therefore, we examined the influence of land degradation by sand accumulation on soil quality through its effects on soil microbial properties.

Soil quality is a key issue in agriculture ecosystem (Stenberg 1999; Chapin III *et al.* 2002), and it is closely related to soil microbiological properties, such as soil microbial biomass, microbial abundance, and enzyme activities. And the soil microbiological properties are commonly used as bioindicators to assess soil quality (Schloter *et al.* 2003; Garcia *et al.* 1997; Masciandaro and Ceccanti 1999; Pajares *et al.* 2010). Firstly, soil microbial biomass carbon is both a source and/or sink of available nutrients, and it regulates soil carbon storage (Jia *et al.* 2010). Secondly, microorganisms take part in the process of litter decomposition, soil humus formation and soil nutrient circulation (Powlson *et al.* 1987; Zhang *et al.* 2006), and microbial abundance reflects the quality of the soil environment (Wang *et al.* 2011). Soil enzymes play an important role in the material cycle and energy flow in soil environment, and they are specific biological catalysts in biochemical reactions in soils (Burns 1978; Li 1996). In addition, microbiological activities can provide information on important biochemical processes (e.g. degradation potential) that affect soil function and which, in turn, are affected by agricultural practices (Trasar-Cepeda *et al.* 2000). Previous studies in different regions have shown that soil microbial biomass and enzyme activities are significantly affected by tillage (Kandeler *et al.* 1999; Hamido and Kpomblekou 2009), cropping systems (Klose 1999; Moore *et al.* 2000; Ekenler and Tabatabai, 2004) and land use (Acosta *et al.* 2003). Hence, it is necessary to examine soil microbiological properties to maintain or improve soil quality in agricultural ecosystem, especially in semi-arid area (García-Orenes *et al.* 2010).

Horqin sandy land is located in the semiarid agro-pastoral zone of Inner Mongolia in northern China. During recent decades, it has undergone severe desertification, primarily due to overgrazing and over-cultivation, and rapid population growth has led to the conversion of large areas of natural sandy grassland into cropland (Zhao *et al.* 2007a). In this region, corn (*Zea mays* L.) monocultures dominate the cultivated land. During windy seasons, it is reported that the rate of airborne dust deposition varies greatly from 13 to 1254 kg ha^{-1}, averaging 232 kg ha^{-1} per day, in Horqin sandy land croplands (Li *et al.* 2004). The accumulated sand in cropland delays corn life cycle, and decreases aboveground biomass and seed yield (Zhao *et al.* 2006). However, how the sand accumulation influences soil quality through its impact on the soil microbial biomass and microbiological activities still remains unclear.

The objectives of this study are to: (1) investigate soil microbial biomass carbon and microbiological activities along a cropland degradation gradient, and (2) examine the relationships between soil microbial biomass carbon and soil microbiological activities.

Materials and methods

Study area

The study area is located in the village of Yaoledianzi (42°55’N, 120°42’E; 360 m a.s.l.) in Naiman County in the middle part of Horqin sandy land, China. The climate here is temperate, semiarid continental monsoonal, with an average annual precipitation of 360 mm, more than 75% of which falls in the growing season of June–September. The annual mean pan-evaporation is around 1935 mm. Annual mean temperature is approximately 6.4 °C, and the lowest monthly mean temperature is -13.1 °C in January, while the highest is 23.7 °C in July. Annual mean wind velocity ranges from 3.2 to 4.1 m s^{-1}, and the dominant wind is southwest to south in summer and autumn and northwest in winter and spring. Wind erosion often occurs from April to mid-June before the rainy season arrives (Zhu and Chen 1994). The zonal soil is sandy chestnut, sandy in texture, light yellow in color and loose in structure, making it vulnerable to wind erosion (Zhao *et al.* 2007a). Thickness of the soil layer in the cropland is about 30-45 cm. Corn (*Zea mays* L.) monoculture dominates the cultivated land and yields vary greatly depending on soil properties and terrain (Li *et al.* 2004).

Cropland degradation

Sand accumulation is recognized as one of the primary forms of desertification, and consequent cropland degradation, in the downwind cropland in this region (Zhao *et al.* 2006). Cropland degradation gradient was characterized with a "space-for-time substitution" approach (Zhao *et al.* 2009), and divided into lightly degraded (LDC), moderately degraded (MDC) or heavily degraded cropland (HDC) based on the depth of accumulated sand (Figure 1 and Table 1). Soil characteristics of the degraded croplands are shown in Table 2.

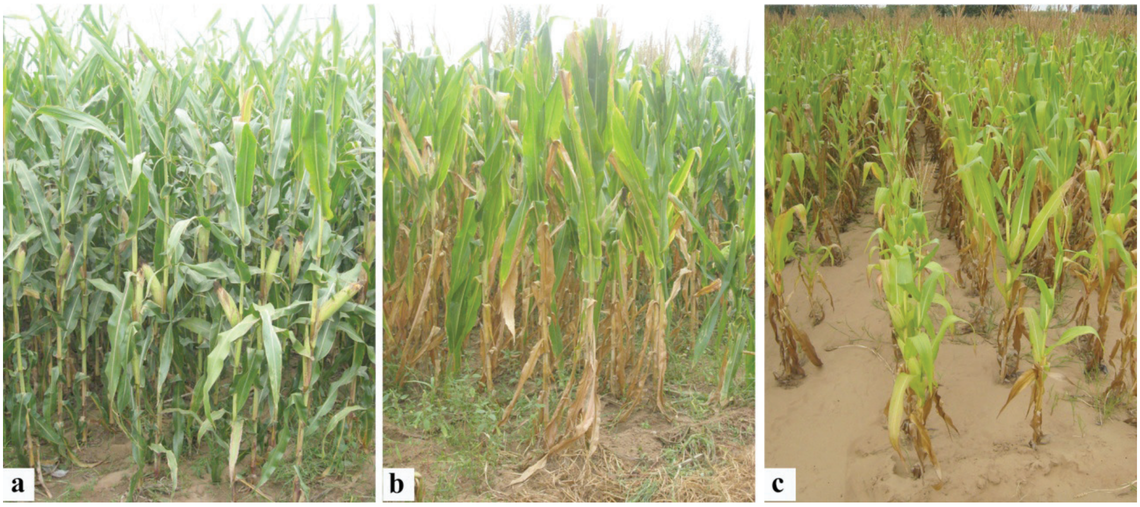

Figure 1: Degraded croplands, a: lightly degraded cropland, b: moderately degraded cropland, c: heavily degraded cropland

Table 1: Characteristics of the different stages of cropland degradation

Cropland classification	Abbreviation	Depth (cm) of deposited sand	Description of the deposited sand layer
Lightly degraded cropland	LDC	2 ± 1 $_{a}$	Lower than 50% of the field ridge.
Moderately degraded cropland	MDC	10 ± 2 $_{b}$	Almost even with the field ridge
Heavily degraded cropland	HDC	15 ± 4 $_{c}$	More than 5 cm higher than the field ridge

Values (mean ± SE) with different letters within a column are significantly different at $P < 0.05$.

Experimental design and soil sampling

The experiment was conducted in August 2010. A 200 m × 200 m study plot was established in each of the lightly degraded, moderately degraded and heavily degraded croplands.

Corn was sown on May 15 in rows parallel to the prevailing wind direction with a row spacing of 40 cm, and plant spacing of 20 cm. Five quadrates (2 m × 2m) were established in each plot, and spaced about 10 m apart. In all quadrates, soil cores were collected to a depth of 0-20 cm, and a pooled sample was made by mixing five sub-samples from five locations in each quadrat. Every pooled sample was sieved (< 2 mm) to remove rocks and plant materials, and stored separately in ziplock bags. All samples were stored at 4 °C for the examination of microbiological attributes.

Table 2: Soil characteristics of the degraded croplands

Attributes	**Cropland types**		
	LDC	**MDC**	**HDC**
Organic carbon C (g kg^{-1})	$10.28 \pm 0.10_a$	$2.86 \pm 0.07_b$	$0.97 \pm 0.02_c$
Total nitrogen N (g kg^{-1})	$0.75 \pm 0.02_a$	$0.26 \pm 0.01_b$	$0.11 \pm 0.01_c$
C/N ratio	$13.73 \pm 0.41_a$	$11.33 \pm 0.93_b$	$8.55 \pm 0.49_c$
pH	$8.32 \pm 0.08_a$	$8.46 \pm 0.12_a$	$7.74 \pm 0.09_b$
EC (μS cm^{-1})	$107.12 \pm 10.41_a$	$80.33 \pm 10.04_a$	$44.18 \pm 6.51_b$
Soil Water Content (%)	$7.87 \pm 0.29_a$	$6.13 \pm 0.19_b$	$4.95 \pm 0.03_c$
Particle size distribution (%):			
Coarse sand (2-0.10 mm)	$58.74 \pm 2.82_a$	$82.56 \pm 3.21_b$	$94.34 \pm 3.07_c$
Fine sand (0.10-0.05 mm)	$35.62 \pm 1.15_a$	$14.55 \pm 1.30_b$	$4.50 \pm 0.61_c$
Clay (<0.05 mm)	$5.64 \pm 0.49_a$	$2.89 \pm 0.32_b$	$1.16 \pm 0.31_c$

Values (mean ± SE) with different letters within a row are significantly different at $P < 0.05$.

Analyses methods

Microbial biomass carbon (MBC) was assessed by using the chloroform fumigation-extraction method (Jia *et al.* 2010; Vance *et al.* 1987; Yao and Huang 2006). Culturable soil microbial abundance was determined as colony-forming unites (CFU) by the pour plate method (Xu and Zheng 1986; Collins *et al.* 1995). Nutrient agar (for bacteria), modified Gause's synthetic agar (for actinomycetes), rose bengal agar (for fungi), modified Ashby N-free agar (for azotobacters) and Hutchinson agar (for cellulose decomposers) mediums were used to culture microbial groups. Bacteria, actinomycete and fungi counts were conducted after incubation of the plates at 28-30 °C for 2-5 days. Azotobacter and cellulose decomposer counts were conducted after incubation at 28-30 °C for 15-20 days under aerobic conditions. Soil enzyme activities were assayed using the methods of Tabatabai (1982) and Guan (1986). Dehydrogenase activity (DEHa) was assessed by the TTC method. Peroxidase activity (PERa) was assessed by the potassium permanganate titration method. Protease activity (PROa) was assessed using the gelatin hydrolyzation method. Urease activity (UREa) was assessed using the nesslerization colorimetric analysis. Cellobiohydrolase activity (CELa) was assessed using the anthrone colorimetric analysis.

Data analyses

Data were analyzed and described by SPSS 17.0 and Origin 8.0 for Windows. Values were presented as mean ± SE, and significant differences among treatment values were calculated by one-way analyses of variance (ANOVA). Least significant difference (LSD) tests were performed to evaluate differences among individual treatments. Correlations between microbial biomass carbon and microbiological activities were analyzed using Pearson’s 2-tailed tests. Stepwise regression analysis assigned soil microbial biomass carbon as dependent variables, and soil microbiological activities as independent variables. Independent variables were allowed to enter the model when $P<0.05$ and not when $P>0.10$.

Results

Changes in soil microbial biomass carbon

Soil microbial biomass carbon (MBC) significantly decreased along the cropland degradation gradient (Figure 2). MBC decreased as the level of degradation increased. There was 52.22% decrease from LDC to MDC, and a 94.37% from LDC to HDC.

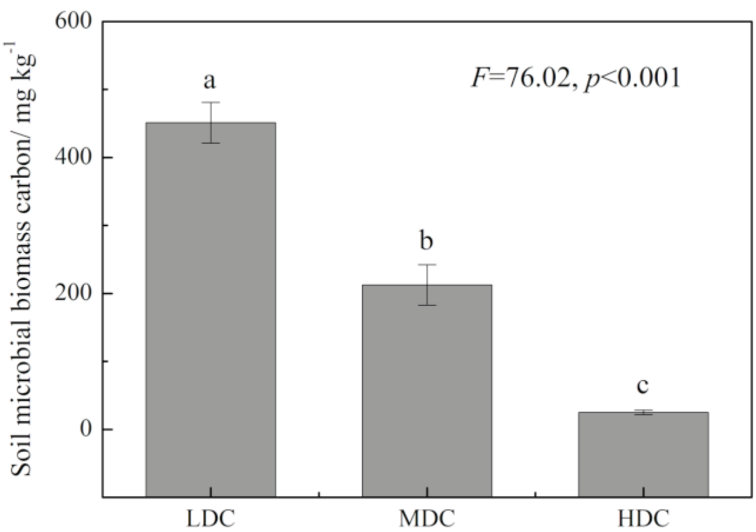

Figure 2: Soil microbial biomass carbon along the cropland degradation gradient. Values (mean ± SE) with different letters are significantly different at $P < 0.05$.

Changes in aerobic microbial group abundance

The abundance of bacteria, actinomycete, fungi, azotobacters and cellulose decomposers decreased significantly from LDC to HDC (Table 3). The number of colony-forming units (CFU) of three basic microbial groups decreased 29.60% and 40.75% (bacteria), 34.45% and 73.30% (actinomycetes), 31.64% and 76.96% (fungi) from LDC to MDC and LDC to HDC, respectively. CFU of azotobacters and cellulose decomposers were 40.91% and 74.03%, 13.06% and 61.82% lower in MDC and HDC, respectively, than in LDC. Thus, percentage decrease in microbial biomass carbon with increasing sand accumulation was higher compared to the percent decrease in the number of CFU. This was most likely caused by a decrease in the proportion of fungi, which made up less than 5% of the total microbial abundance but over 40% of total microbial biomass (Guo and Zhu 1997).

Table 3: Abundance of aerobic microbial groups affected by cropland degradation

Cropland type	CFU × 10^3 g^{-1} dry soil			CFU g^{-1} dry soil	
	Bacteria	Actinomycetes	Fungi	Azotobacters	Cellulose degraders
LDC	1265.43±57.31 $_a$	548.49±47.63 $_a$	19.17±2.32 $_a$	51 ± 5 $_a$	203 ± 8 $_a$
MDC	890.89±60.61 $_b$	360.60±49.29 $_b$	13.26±1.21 $_b$	30 ± 3 $_b$	174 ± 7 $_a$
HDC	701.05±72.04 $_b$	146.73±14.55 $_c$	4.39±0.59 $_c$	13 ± 2 $_c$	77 ± 4 $_b$
F value	20.34	24.67	65.92	38.52	98.97
P	<0.001	<0.001	<0.001	<0.001	<0.001

Values (mean ± SE) with different letters within a column are significantly different at $P < 0.05$.

Changes in soil enzyme activities

Soil enzyme activities also changed significantly along the cropland degradation gradient (Table 4). DEHa ranged from 4.95 to 46.24 μg TPF · g^{-1} dry soil · $24h^{-1}$, and decreased by 22.84% from LDC to MDC and 82.13% from LDC to HDC. PERa ranged from 19.53 to 411.25 μmol H^+ · g^{-1} dry soil · $1h^{-1}$, and decreased by 39.75% from LDC to MDC and 92.87% from LDC to HDC. PROa ranged from 15.12 to 79.77 μg NH_3-N · g^{-1} dry soil · $24h^{-1}$, and decreased by 33.14% from LDC to MDC and 69.10% from LDC to HDC. UREa ranged from 8.52 to 397.04 μg NH_3-N · g^{-1} dry soil · $24h^{-1}$, and decreased by 36.33% from LDC to MDC and 97.40% from LDC to HDC. CELa ranged from 14.33 to 89.36 μg glucose · g^{-1} dry soil · $24h^{-1}$, and decreased by 60.10% from LDC to MDC and 79.52% from LDC to HDC. Therefore, all enzyme activities decreased with increasing cropland degradation.

Table 4: Characteristics of soil enzyme activity along the cropland degradation gradient

Enzyme activities	Cropland	Mean*	SD	Max	Min	*F* value	*P*
DEHa (μg TPF · g^{-1} dry soil · $24h^{-1}$)	LDC	40.67 $_a$	4.89	46.24	35.43	131.34	<0.001
	MDC	31.72 $_b$	2.75	35.36	28.08		
	HDC	7.27 $_c$	1.62	8.65	4.95		
PERa (μmol H^+ · g^{-1} dry soil · $1h^{-1}$)	LDC	403.67 $_a$	11.85	411.25	390.81	106.34	<0.001
	MDC	251.33 $_b$	10.02	259.60	240.22		
	HDC	28.33 $_c$	7.67	35.67	19.53		
PROa (μg NH_3-N · g^{-1} dry soil · $24h^{-1}$)	LDC	71.68 $_a$	6.81	79.77	64.91	85.20	<0.001
	MDC	47.82 $_b$	6.32	55.13	38.94		
	HDC	22.20 $_c$	4.63	27.22	15.12		
UREa (μg NH_3-N · g^{-1} dry soil · $24h^{-1}$)	LDC	368.28 $_a$	22.59	397.04	339.36	568.10	<0.001
	MDC	234.56 $_b$	18.89	257.92	207.92		
	HDC	9.55 $_c$	0.88	10.56	8.52		
CELa (μg glucose · g^{-1} dry soil · $24h^{-1}$)	LDC	84.79 $_a$	3.77	89.36	80.77	504.36	<0.001
	MDC	33.83 $_b$	3.84	39.61	30.19		
	HDC	17.35 $_c$	2.79	21.11	14.33		

DEHa: dehydrogenase; PERa: peroxidase; PROa: protease ; UREa : urease; CELa: cellobiohydrolase. *Mean values with different letters in each enzyme activity among three croplands are significantly different at $P < 0.05$.

Relationship between soil microbial biomass carbon and microbiological activities

Pearson's correlations between microbial biomass carbon and the abundance of microbial groups (bacteria, actinomycete, fungi, azotobacter and cellulose decomposer) were significantly positive, and correlations between microbial biomass carbon and enzyme (dehydrogenase, peroxidase, protease, urease and cellobiohydrolase) activity were also significantly positive (Table 5).

Stepwise regression analysis was used to identify the microbiological factors that best predict soil microbial biomass carbon. It demonstrated that soil microbial biomass carbon (MBC) was significantly related to cellobiohydrolase activity (CELa), and the abundance of azotobacter (Azo) and actinomycete (Act). The relationship is described by the following equation:
MBC= -147.944+5.451CELa+2.090Azo-0.053Act; (R^2=0.971, F=122.941, P<0.001).

Table 5: Pearson's correlations between soil MBC and microbiological activities

Microbiological activities	Microbial biomass carbon
Bacteria	0.747*
Actinomycete	0.768**
Fungi	0.932**
Azotobacter	0.889**
Cellulose decomposer	0.859**
Dehydrogenase (DEHa)	0.850**
Peroxidase (PERa)	0.911**
Protease (PROa)	0.905**
Urease (UREa)	0.930**
Cellobiohydrolase (CELa)	0.932**

*Correlation is significant at 0.01 (2-tailed), ** Correlation is significant at 0.001 (2-tailed).

Discussion

Response of soil microbial attributes to cropland degradation

Soil microbial biomass carbon and microbiological activities responded strongly to cropland degradation caused by sand accumulation. Microbial biomass carbon, microorganism abundance, and soil enzyme activities decreased significantly as the level of degradation of the cropland increased. In our study, cropland degradation was caused by accumulated sand, which mostly came from eroded areas of windward regions, such as mobile dunes, semi-mobile dunes and windward croplands. This sand accumulation changes soil particle size distribution, soil bulk density, water holding capacity and soil nutrient contents (Li 2004; Su *et al.* 2004). As a result, microbial abundance and enzyme activities were greatly affected. Simultaneously, this change in soil characters influences crop growth, and alteres the respiration and secretion of crop roots, as well as the litter input from crops (Zhao *et al.* 2006). Ultimately, soil microbial biomass carbon, which is primarily produced by microorganisms, was affected by sand accumulation in croplands.

Relationship between soil microbial biomass carbon and microbiological activities

Soil microorganisms determine microbial biomass, and maintain soil functional activities. They represent the main source of soil enzymes that regulate the cycling of elements in soils (Böhme and Böhme 2006), and they also control the decomposition of organic matter (Powlson 1987; Landgraf and Klose 2002), as soil enzyme activities are closely linked with microbial production in the process of litter decomposition (Sinsabaugh *et al.* 2008). Correlation analyses show that microbial biomass carbon was significantly correlated with soil microbiological activities, including the abundance of microbial groups and enzyme activities, supporting the assertion that most soil microbial biomass carbon was produced by soil microorganisms, which were the main source of soil enzymes (Böhme and Böhme 2006; Madejón *et al.* 2007).

Microbiological activities, including the abundance of microbial groups and enzyme activities, were highly correlated with soil microbial biomass carbon in degraded croplands. The model analyzed by stepwise regression showed that soil microbial biomass carbon was significantly affected by cellobiohydrolase activity, azotobacter and actinomycete abundance. Cellobiohydrolase catalyzes litter into small elements for plant uptake (Debosz *et al.* 1999) and azotobacters transform N_2 into NH_3-N and/or NO_3-N for plant consumption, which are two main sources of soil nutrients in these sandy croplands (Doty 2011). Actinomecete form a large part of the microbial biomass (Li 1996).

Conclusion

The degradation of cropland caused by accumulated sand in Horqin sandy land of Inner Mongolia resulted in a significant decrease in soil microbial biomass and microbiological activities. In addition, correlations between microbial biomass carbon and microbiological activities were significantly positive. Microbial biomass carbon was closely related with cellobiohydrolase activity, azotobacter and actinomycete abundance. In Horqin sandy land, a strong windy season occurs in spring, and erodes the dry, bare surface soil in sandy dunes and windward croplands. Sand is deposited in leeward croplands, and consequently causes soil degradation and reduces not only the productivity and yield in these croplands, but also the characteristics of microbiological attributes.

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Removal of salinity from soil surface by a water-saving leaching method

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Abstract

Salt accumulation occurs in a very thin soil surface layer and in a spot state in an early stage. In this stage, leaching should be conduct for only the salt accumulation zone. Surface Suction Leaching Method (SSLM) developed by authors, can do such salt removal using a little water. An instrument for SSLM consisted of three parts - water supply, drainage and insert parts. The water supply part had a storage tank for leaching water and a flowing pump. The drainage part had a vacuum pump and a collection tank for soil water. The insert part was a disc-shaped container with a stainless guide for inserting into soil, a ceramic filter, and an inlet/outlet pipe with a bidirectional cock. It was directly inserted into a salt accumulated zone on soil surface. Through the cock, the inlet/outlet pipe was connected with the water supply and drainage parts, respectively. An operator could select the stages of water supply for leaching and collection of soil water for removal of salts by changing the cock. In this study, the method was applied into sandy soil with artificial salt accumulated soil layer with 15 dS/m. As results. The process could remove 80 % of accumulated salts and collect 93 % of leaching water from the soil layer. SSLM was thus a useful water saving desalinization method.

Introduction

Excess soil salinity, especially in the world's arid and semi/arid regions, is one major cause of decreasing agricultural production. The total area of such salt-affected soil is estimated to be about 955 million hectors (Szabolcs 1994). Since trends suggest that it is increasing, we need to establish countermeasures.

Desalinization of salt-affected fields is crucial for sustainable agriculture in arid/semi-arid lands. Techniques for combating salt-accumulation problem and ameliorating salt-affected soil in areas with sufficient water include leaching, surface flushing, biological reduction, and a combination of leaching and biological reduction (Qadir *et al.* 2000). Leaching, which is the most prevalent method, temporarily moves excess salts to the lower soil layers, but after the crop is harvested, the salt easily returns to the surface layers in impermeable soils (Yamamoto 2009). A defect of ordinary leaching methods is the percolation of the salts of the surface layers into the lower layers. Farm land in arid or semi-arid regions has open channels to remove leachate out of the field. Although an open-channel drain is an ordinary facility for the salt and water management of a field, in many cases, it doesn't remove salts from fields in arid or semi-arid regions (Kitamura *et al*. 2006). Consequently, leaching tends to cause secondary salt accumulation in such fields.

To the best of our knowledge, there are two physical amelioration methods for salt-affected soil in water-scarce areas. One is scraping (FAO 1998) and the other is hydration (Abe *et al.* 1995). The scraping method does not need any water because it directly excavates the salt-affected soil by mechanical means. However, it needs large storage space for the removed soil and has no means to treat the soil. In the hydration method, the saline water in a soil surface layer is absorbed by a thin sheet lying on the soil surface. Only salts remain in the sheet because the absorbed water is rapidly evaporated under the dry conditions of the arid regions. Although it is certainly a water-saving scheme, this passive method strongly depends on soil surface evaporation. Moreover, its desalinization efficiency is very small. At present, therefore, an amelioration method for salt-affected soil in the water-scarce areas remains un-established.

Excess salt accumulation occurs at the soil surface. It is generated at small local points in a field in the early stage. It is wasteful to apply ordinary leaching or surface flushing methods to such fields because the water for amelioration is also poured onto the sound parts of the same field. Since it is efficient to directly remove the salts from the accumulated parts under this condition, we developed a new method that can directly desalinize such a small saline part. In this study, we experimentally assessed the desalinization performance of this method using a soil column with an artificial salt-accumulated surface layer.

Surface suction leaching method

Theory

We developed a new desalinization method for local salt accumulation. In this method, a little water is directly poured into a salt-accumulated part on the soil surface. Since the amount of water is so little that it is not drained off by gravity, the water is retained in the soil pores of the surface layer and it dissolves the accumulated salts. The saline water is sucked up at the soil surface before it could move down to the lower layers. Therefore, we called our method a surface suction leaching method (SSLM) that saves water because the gravity loss is very small.

Apparatus for surface suction leaching method

The SSML apparatus consists of three parts: a water supply part (SP), a soil insert part (IP) and a drainage part (DP). Figure 1 shows its schematic view. The SP has a feeding pump and a storage tank for leaching water. The tank is connected to the IP through the feeding pump. The leaching water is supplied from the IP's ceramic filter into the soil surface. The water becomes saline due to dissolution of accumulated-salts in the surface layer. After that, the saline water is sucked up from the soil surface into the IP through the filter. This water is sent from the IP to the DP. Both SP and DP are connected to the IP through the same bidirectional cock, which manually switches them. That is, the water supply and the soil water suction are changed by manually switching this bidirectional cock. The DP consists of a drainage tank and a vacuum pump. The saline water is sucked up by the IP by the vacuum pump and is stored in the drainage tank. The tank's pressure, which is reduced by the vacuum pump, is the driving force to suck up the saline water from the soil.

Among the three parts, the inserted part is the most important. Figure 2 shows its detailed structure. The IP is equipped with a stainless steel guide that allows it to be inserted in the soil down to 1.0 cm□Its bottom is a 10-cm diameter, 0.5-cm thick glass filter that contacts with soil surface by a paper filter. It has two exhaust valves on its upper side. When leaching water is conveyed from the SP, air is pushed out of a chamber over the ceramic filter through these valves by the leaching water. These valves are closed after the chamber is filled with water.

Desalinization process

Desalinization occurs in the apparatus in the following procedure (Fig. 3):
Step 1: The SSLM apparatus is set on the field, and the IP is directly inserted into a salt accumulation point.
Step 2: The leaching water is conveyed from the SP tank to the IP by the feeding pump. The water infiltrates the soil surface layer and dissolves the accumulated-salts in it. The amount of irrigation water is so small that it doesn't percolate into the lower layers.
Step 3: After switching the bidirectional cock, the saline soil water is sucked up by the vacuum pump and stored in the DP's drainage tank. The pump continues to extract soil water until its collection becomes impossible.
Step 4: The bidirectional cock is switched to the SP for the next cycle.

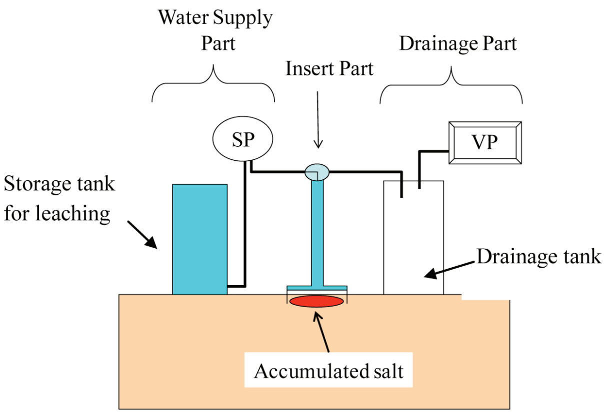


Figure 1: Schematic view of apparatus for surface suction leaching method.SP and VP mean a seeding pump and a vacuum pump.

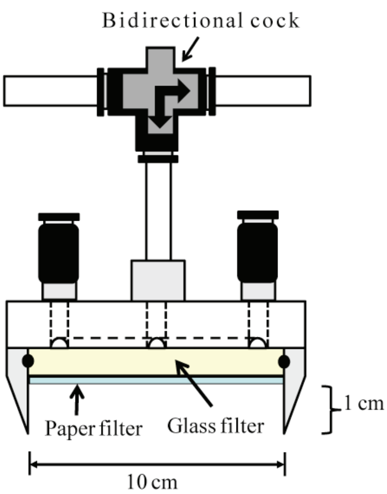


Figure 2: IP structure

One desalinization cycle of this procedure consists of Steps 2 to 4. The operator repeats a cycle until the salinity concentration reaches a target value.

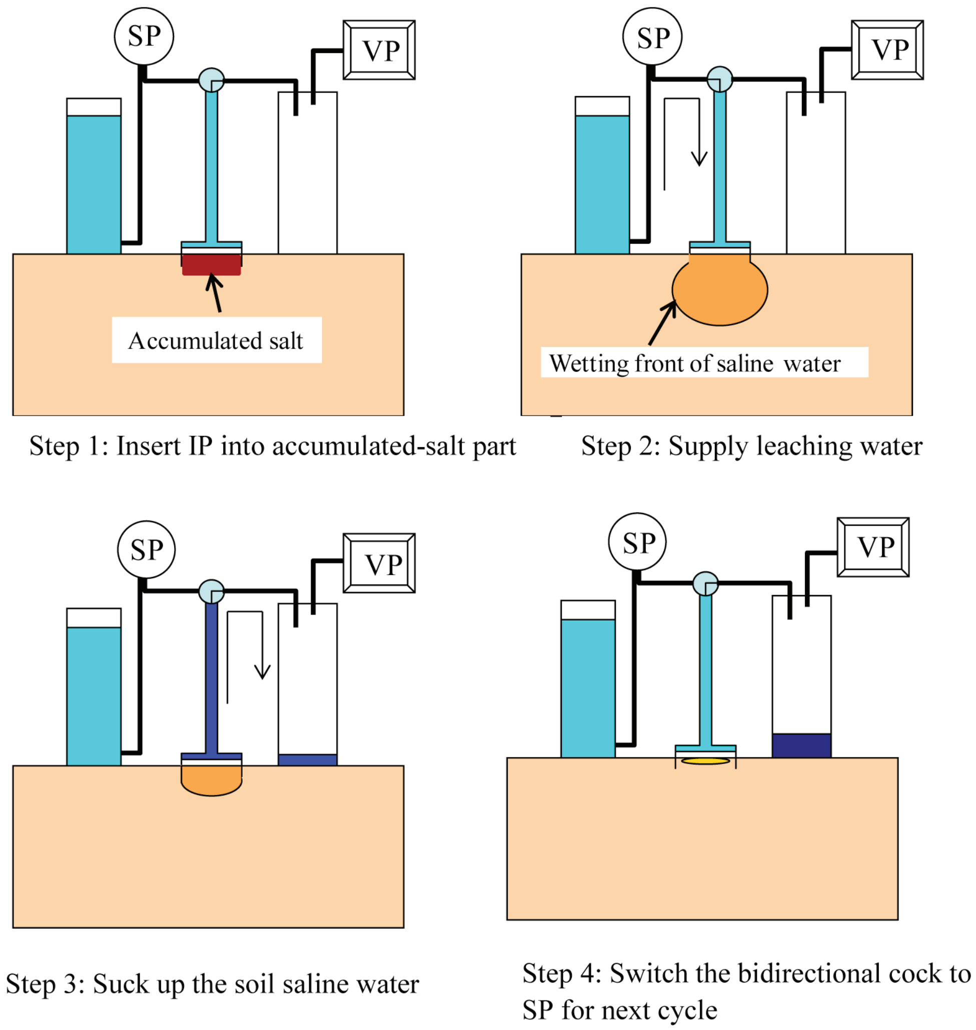


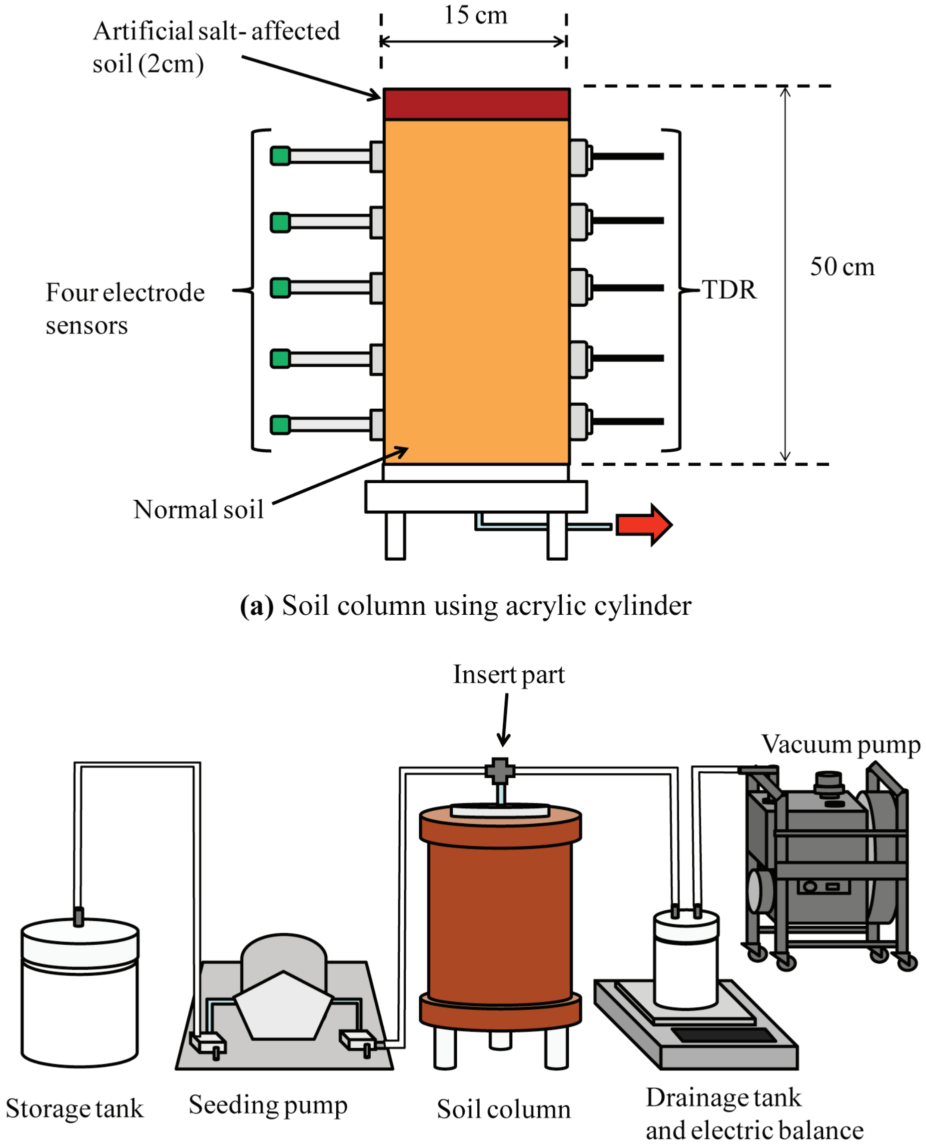
Figure 3: Desalinization process for surface suction leaching method.

Experimental method

Soil column and materials

Soil column experiments were conducted in a laboratory to assess the desalinization performance of our surface suction leaching method. A schematic view is shown in Figure 4.

Fig. 4(a) shows the details of a soil column using an acrylic cylinder, and Fig. 4(b) is the entire image of the desalinization experiment using the SSLM apparatus and the column. We used a 15-cm diameter, a 50-cm deep acrylic cylinder for our experiments. Its bottom was a glass filter with a saturated hydraulic conductivity, Ks, of 2.99×10^{-3} cm/s. A pressure head of -27 cm as suction was given to the bottom. Volumetric water content (θ) and the electric conductivity of the soil pore water (EC_p) were measured by time domain reflectometry (TDR) and four electrode sensors (FES) that were installed at depths of 5, 15, 25, 35 and 45 cm of the column.



(a) Soil column using acrylic cylinder

(b) Whole image of soil column experiment

Figure 4: Schematic view of soil column experiment

Two cylinders were prepared for the experiment. One was packed with sandy soil with a bulk density of 1.3 g/cm^3, and the other was loamy sand soil with a bulk density of 1.5 g/cm^3. Both the sandy and the loamy sand soils with an electrical conductivity of saturation extract (EC_e) of 15 dS/m were created as salt-accumulated soils. After air-drying the soil, it was laid on the surface of each soil column within 2-cm deep.

Desalinization experiment

The IP was inserted on the surface of the soil column. The leaching water was tap water with EC of 0.085 dS/m. Four-hundred gram of it was used for each experiment. The soil saline water was stored in the DP's drainage tank whose weight was automatically measured by an electric balance.

EC of the soil saline water (EC_w) and EC_e of soil were measured at the end of experiment. The conditions for operating the SSLM were empirically determined by trial and error (Table 1). The flux of the water supply depended on the soil's hydraulic conductivity. When excessive flux is given to the IP for low permeability soil, the water can not immediately infiltrate into the soil and flow back to the IP. This condition causes the apparatus to stand precariously or to fall to the soil surface. Therefore, the flux for the loamy sand soil's column was smaller than the sandy soil. The other operation conditions were the same between the sandy and loamy sand soils. To determine the EC_e profile, soil sampling was done in 1-cm increments from zero to 42 cm below the soil at the end of each experiment.

Table 1: Conditions of operating apparatus for surface suction leaching method

Soil	Flux of water supply (cm/s)	Duration of water supply (s)	Duration of suction (s)
Sandy soil	$10^{-2}\times5.1$	10	110
Loamy sand soil	$10^{-2}\times1.3$	10	110

As comparative experiments, we applied ordinary leaching method to the other two soil columns with a salt-accumulated top layer of 15 dS/m in EC_e. Four-hundred gram of tap water (as leaching water) was quickly poured into the soil column. After 1400 minutes for the sandy soil and 800 minutes for the loamy sand soil, soil sampling was conducted in 1-cm increments from zero to 42 cm below the soil to determine the EC_e profile.

Results and discussion

Figures 5(a) and (b) show the time variations of θ and EC_p in the sandy soil column. Their values were slightly oscillatory but approximately stable regardless of time. Neither the solute nor the water reached 5 cm. The time variation of the drainage tank's weight is shown in Figure 6. The curve of the cumulative weight changed stepwise because much soil water was sucked up at the early stage of Step 3. It means that the suction duration of 110 seconds were too long for the sandy soils. Three-hundred-seventy-one-gram of water was collected which is 92.5 % of the of supplied water. Figure 7 shows the vertical profile of EC_e in the soil before and after the desalinization experiments. EC_e-s at depths of 1 and 2 cm decreased from 15 to 0.88 and 1.38 dS/m, respectively. The surface layer's reduction ratio exceeded 90.8-%. On the other hand, EC_e at 3 cm increased from 0 to 3.5 dS/m. Although part of the leachate was discharged from the salt-accumulated layer down to the lower layers, the effect ranged within 3 cm. The EC of the collected water was 0.91 dS/m, which corresponds to 10.7 times of EC of supplied water. These results indicate that the supplied water dissolved the accumulated-salt and was collected by the SSLM before gravitational drainage.

The time variations of θ and EC_p in the loamy sand soil are shown in Figure 8. The θ and EC_p in the loamy sand soil were stable regardless of the time and resemble the sandy soil. At least, SSLM's leaching approach did not influence the soil conditions below 5 cm. Figure 9 shows the time variation of the amount of collected water in the drainage tank. It took 16 cycles to supply 400 g of the leaching water because the flux was different from that of the sandy soil. The relationship

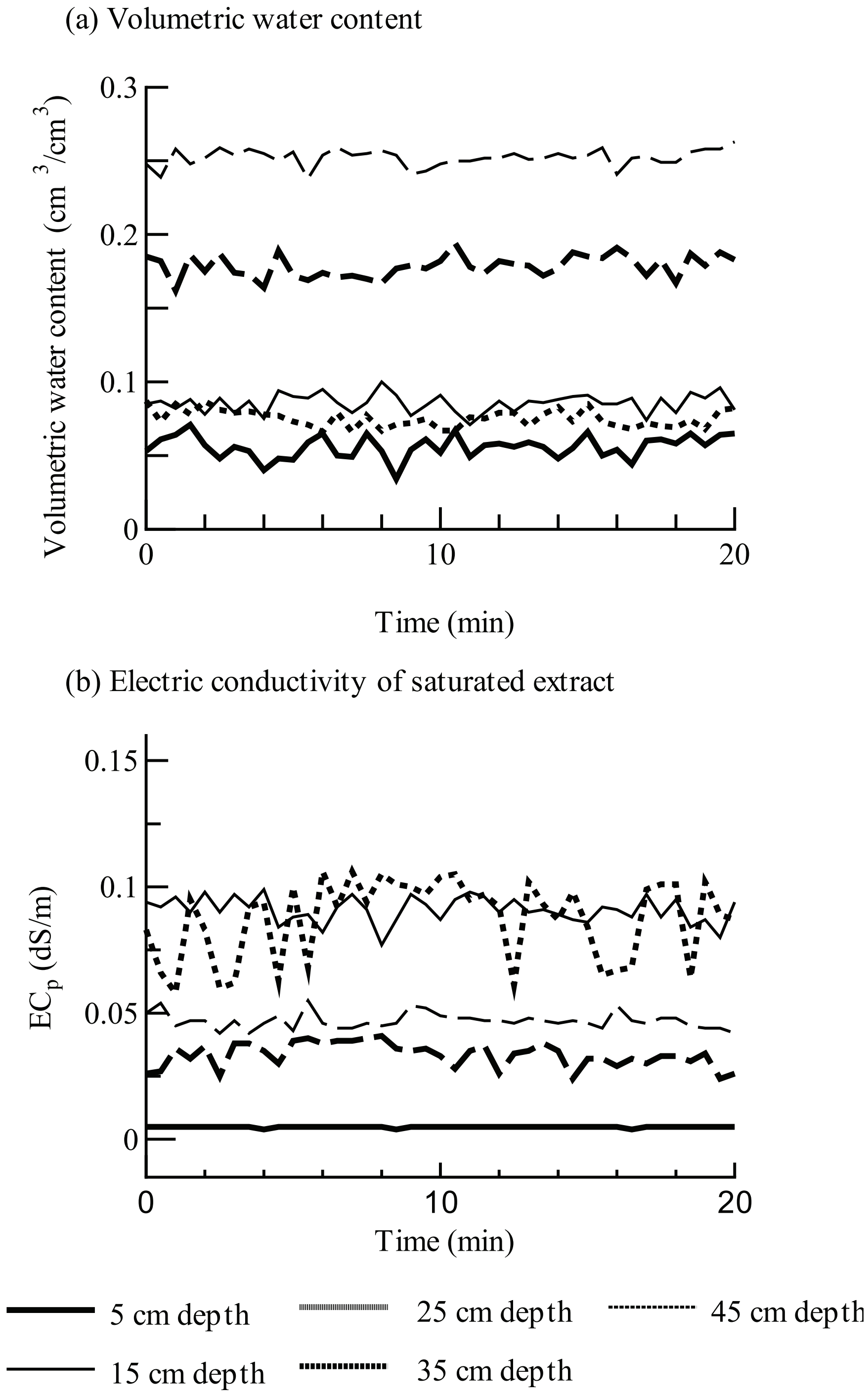


Figure 5: Time variations of volumetric water content and bulk electrical conductivity in soil column

between the time and the amount of collected water was the same as in the sandy soil. Three-hundred-sixty-five gram of water was collected which is 89.1-% of the supplied water. The EC of the collected water was 0.15 dS/m, which was only 1.76 times of the supplied water. Figure 10 shows the vertical profile of EC_e in the soil before and after the experiments. Only the EC_e at 1 cm decreased from 15 to 1.59 dS/m and the lower layer, which was less than 1 cm, kept the initial condition. This result means that the duration of the water supply was too short to reach a depth of 2 cm. As mentioned above, since a suction duration of 110 seconds was obviously too long, for such loamy sand soil we should shorten the suction duration and extend the water supply time. Considering only a 1-cm deep insertion, the reduction ratio of the salinity was 89.4 %.

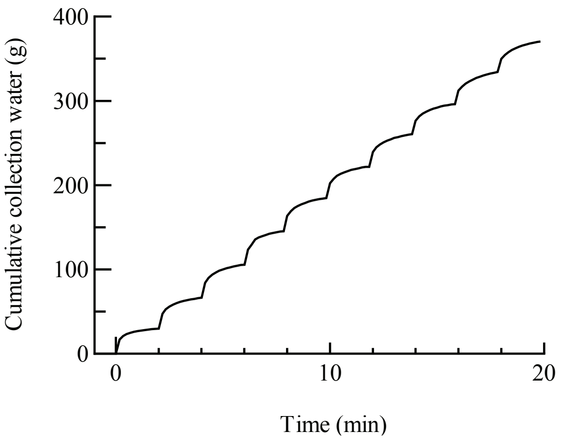


Figure 6: Time variation of amount of collected water by surface suction leaching method.

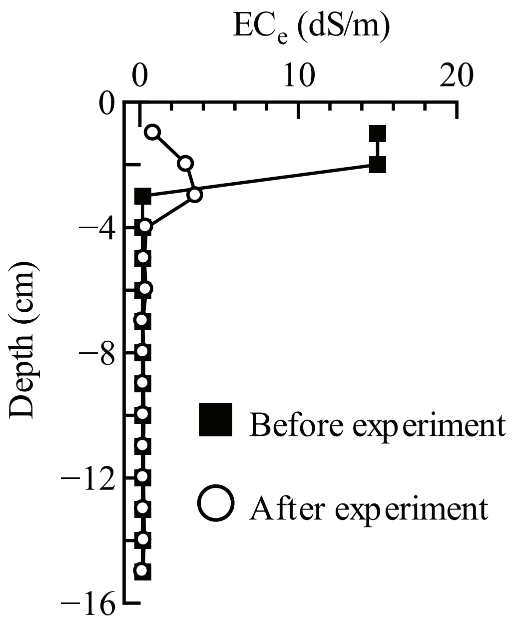


Figure 7: Vertical profile of electrical conductivity of saturated extract of soil before and after desalinization experiment.

These results indicate that SSLM effectively removed the accumulated-salt in the soil surface layer without percolation loss of salinity to lower layers. On average, SSML collected 90.8 % of the leaching water. Since the water's salinity was not so high, it can be re-used for desalinization. From this standpoint, we consider that SSML is a water-saving desalinization method.

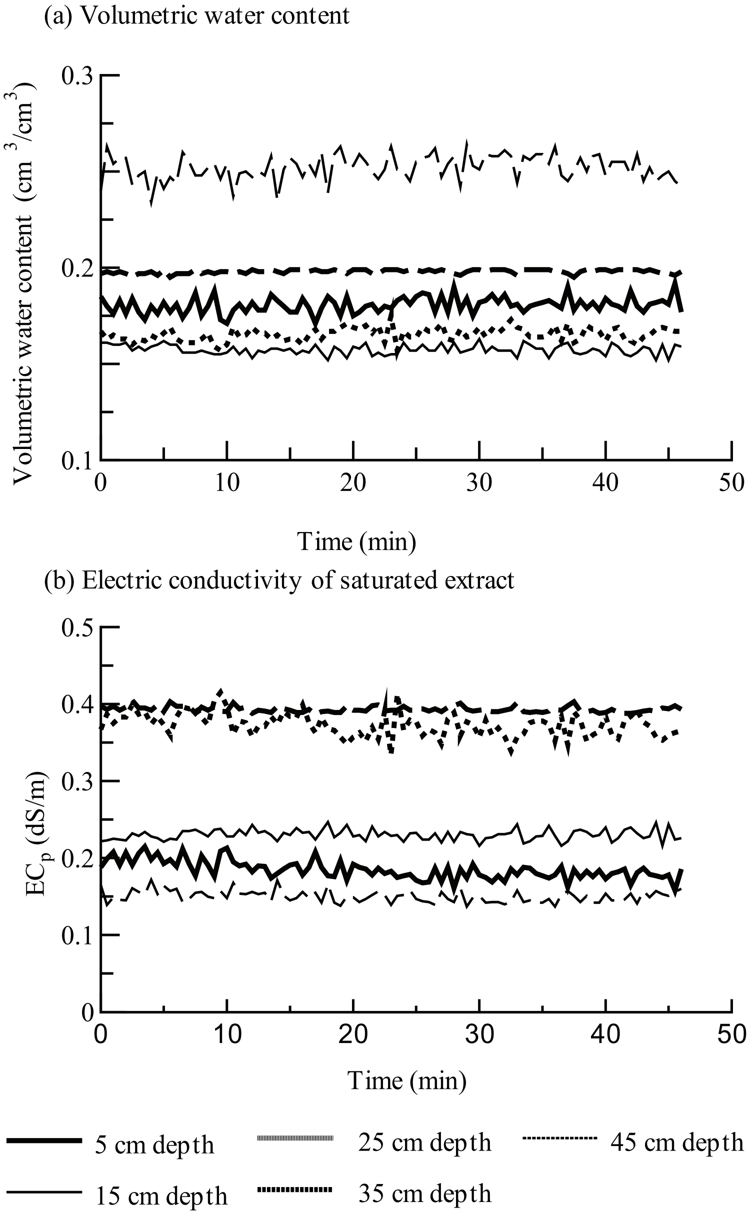


Figure 8: Time variations of volumetric water content and bulk electrical conductivity in loamy sand soil column.

Figure 11 shows the vertical profiles of the electrical conductivity of the saturated extract of sandy and loamy sand soils before and after ordinary leaching experiments. Salts percolated into the lower layers in sandy soil in Fig. 11(a), and EC_e at 1-cm deep became 1.4 dS/m. The EC_e-s of the lower layers slightly increased from 0 to 0.2 dS/m. In Fig.11(b), the EC_e of a 2-cm thick surface layer decreased from 15 to 2 dS/m by leaching. However, most of the salts in the 2-cm thick soil surface remained within the 20-cm thick soil layer. There was no drainage from the bottom of the columns in either of these experiments.

Compared with the SSLM results, the ordinary leaching method indicated better performance than SSLM regarding the decrease of salinity from the soil surface layer. However, all of the salts remained in the soil. In this sense, the ordinary leaching method failed to desalinize the soil columns. Therefore the salt might accumulate at the surface layer after leaching in both soils. On the other hand, since SSLM removed a certain level of the accumulated-salts from the soil profile, it is an effective desalinization method under the early stage of salt accumulation.

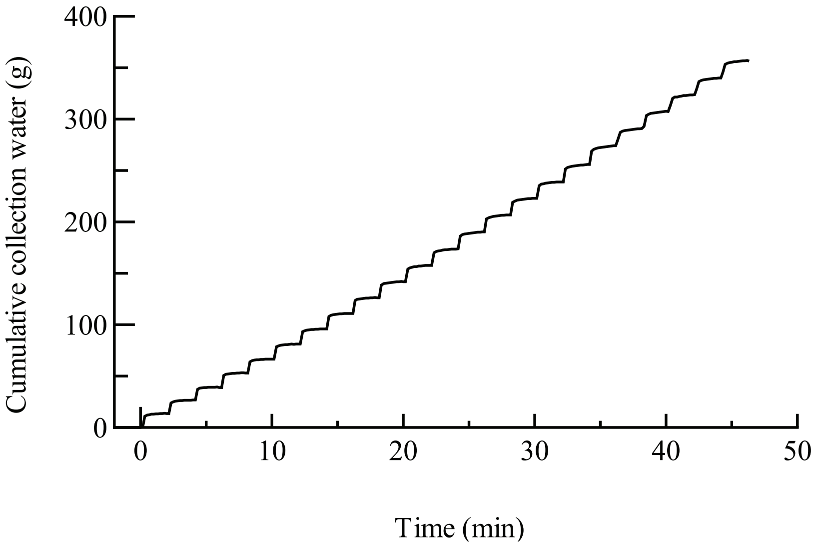


Figure 9: Time variation of amount of collected water by surface suction leaching method for loamy sand soil.

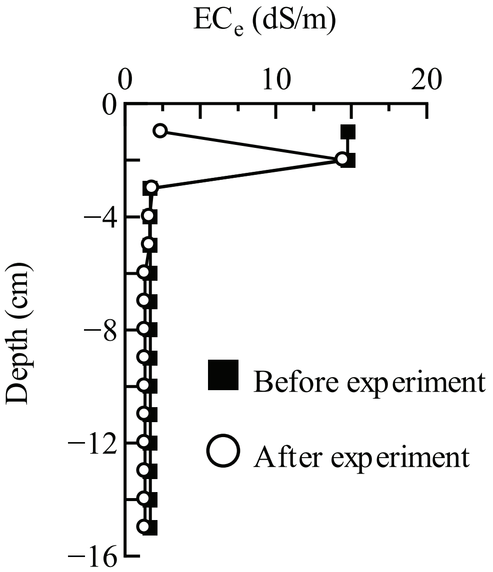


Figure 10: Vertical profile of electrical conductivity of saturated extract of soil before and after desalinization experiment for loamy sand soil.

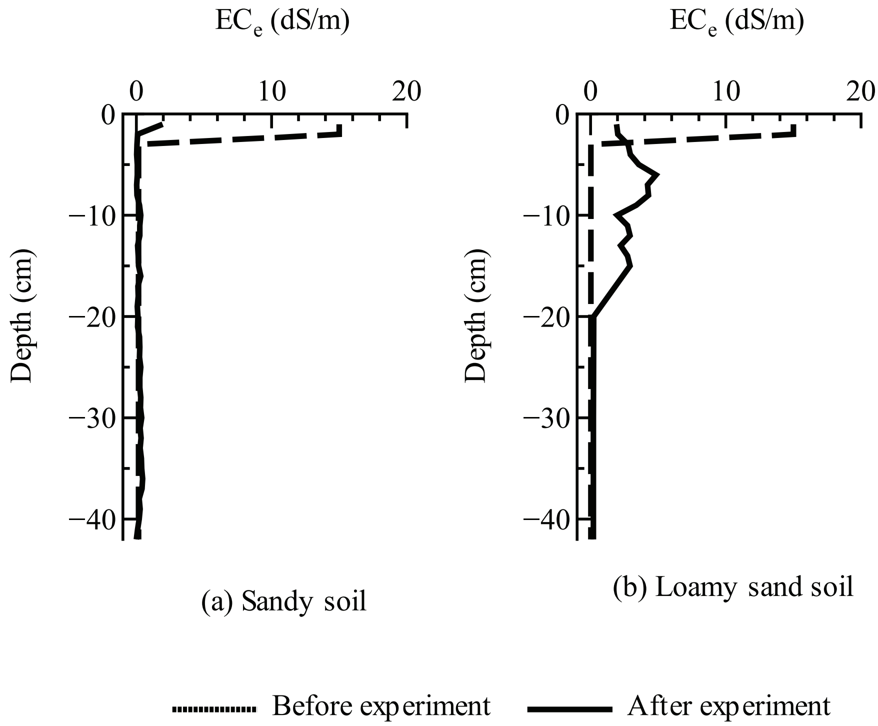


Figure 11: Vertical profiles of electrical conductivity of saturated extract of sandy and loamy sand soils before and after ordinary leaching experiments

Conclusions

In this study, we developed a surface suction leaching method (SSLM) as a water-saving desalinization method and assessed its performance. The following are our results. 1) SSLM collected an average of 90.8 % of the leaching water and the water's EC was not so high. 2) Eighty-percent of the salt in a 2-cm thick surface layer was removed from the sandy soil, 3) Eighty-nine-percent of salts in the 1-cm thick surface soil were removed from the loamy sand soil. 4) Although an ordinary leaching method percolated the accumulated-salts into the lower layers, it could not drain them from the bottom of the soil column: all the salts remained in it.

SSML removed more accumulated-salt from the soil than the ordinary leaching method. From these results, and since the collected water probably can be reused, we conclude that SSLM is an effective water-saving leaching method.

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Theme 6
Sustainable range management and forage production under global climate change

Range management options for sustainable improvement of fodder and livestock production in the dry areas

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Abstract

The dry areas of the world cover an estimated one-third of the earth's surface. More than one billion people (mostly poor) live on such lands. Animals (small ruminants) play an important role in the livelihood of people in the dry areas. In West Asia and North Africa (WANA), rangeland degradation, over the years, has resulted in feed shortage. This manuscript highlights different options to maximize feed productivity in WANA on: Cropland (rain-fed and irrigated), pasture on non-arable lands and rangelands receiving <200 mm. The improvements of feed availability within cropland (rain-fed) include use of legumes such as vetch (*Vicia sativa*, *V. dasycarpa*, *V. narbonensis*) and annual medic. Cereal-shrubs alley farming is an efficient way to utilize cereal stubbles under rain-fed agriculture. In the Arabian Peninsula, where extensive rangeland degradation has led to the widespread use of irrigated exotic forages, the research focused on identifying new forages that use less water. Pastures lands in West Asia have shown significant improvement as a result of annual application of phosphate fertilizer. Over sowing of rangeland receiving <200 mm rainfall with fodder shrubs significantly improved fodder availability and sheep productivity.

Introduction

The dry areas of the world cover an estimated one-third of the earth's surface. More than one billion people (mostly poor) live on such lands. Animals (small ruminants) play an important role in the livelihood of people in the dry areas. One of the major constraints facing livestock production in the dry areas is feed shortage. Rangelands are the main source of feed for growing population of animals in the dry areas, but these are highly over utilized and degraded. This paper considers what has been learnt and achieved in the past thirty years in the area of integration of livestock production with the improvement of feed availability in the dry areas of West Asia and North Africa (WANA).

Agriculture in WANA is mainly rain-fed with cereals (wheat and barley) being the main crops. Wheat is grown in the wetter zones (>300 mm) either continuously (wheat after wheat) or in rotation with a summer crop. In the latter case, the land is kept fallow for 9 months (from the time of land preparation in September) till the sowing of the summer crop in early June. Barley, on the other hand, is grown in dryer areas (<300 mm) where the crop is grown either continuously (year after year) or alternating with a fallow for a period of 14 months (counting from land preparation in September). These fallows, which are referred to as "short fallow" in the case of wheat and "long fallow" in the case of barley, are mainly to enrich the soil moisture for the benefit of the following crop.

In West Asia, these fallows are kept free of weeds, although this may arise in part from naturally sparse weed population due to the poor nutrient status of the soil in the barley growing areas. In North Africa, fallows provide grazing for livestock. They may be grazed throughout the year, or ploughed in early spring, after much of the weed stand has been grazed.

Research activities (since the early eighties) by the International Center for Agricultural Research in the Dry Areas (ICARDA) in collaboration with National Agricultural Research Systems (NARS) in WANA countries was focusing on forage production on cropland, pasture on non-arable lands and rangelands.

Feed production on cropland (rain-fed)

The production of forage legumes, such as vetch (*Vicia* spp.) and chickling vetch (*Lathyrus* spp.), in rotation with cereals provides an alternative to fallow (Jaradat 1988; Harris *et al.* 1989; Osman *et al.* 1990). In the wetter zones, forage legumes (*Vicia* spp.) can be grazed while green or after maturity, made into hay or harvested at maturity for seed. In the latter case, crop residues have value as animal feed and can be grazed, stored or sold (Halila *et al.* 1990). In the dryer zones, forage legumes (*Lathyrus* spp.) can be grown in rotation with barley and used to meet the needs of animals in each season. Several studies on forage legumes productivity in pure stand, and in mixtures and hay quality have been reported in the eighties (Osman *et al.* 1983; Osman and Nersoyan 1986; Rihawi *et al.* 1987). Hay production from adapted legumes such as vetch and pea (*Pisum sativum*) and from forage cereals such as barley, triticale and oats have been suggested as one way of increasing feed from fallow land in traditional rain-fed cropping areas.

However, growing either legumes or cereals in pure stand is not ideal for hay production. Legumes (vetches and peas) have a twining growth, resulting in difficulties in mechanical harvesting and in poor hay yield. Cereals, although high in dry matter (Robinson 1969; Hadjchristodolou 1973), have rather low feed quality, especially when harvested late. The effects of different seed ratios (cereal-legume) on forage yield and quality and on grain yield of a following barley crop were investigated using vetch-cereal and pea-cereal mixtures (Osman and Nersoyan 1986). The maximum overall yield and quality of forage was recorded for the 2:1 legume-cereal combinations, while the greatest benefit to subsequent barley grain yield was realized when the legume was grown in a pure stand or formed a higher proportion of the mixture. Herbage quality was better in forages containing vetch than those containing pea. It is believed that adoption of barley-forage legume rotation is currently constrained by shortage of seed and fertilizer (Cooper and Baily 1990).

Another alternative to fallow is ley farming (cereal-pasture rotation), based on annual pasture legumes. The system was developed with legumes of Mediterranean origin and widely used in Australia. It has the advantage of low inputs and, if properly managed, the pastures need only be sown once and thereafter are self regenerating. In Australia, the pastures not only fix enough nitrogen for their own needs but also provide much of the requirement of the following cereal. Extensive testing of the system in the Mediterranean region has demonstrated that legume-based pastures are productive, especially when local ecotypes are used. However, adoption of the system by farmers is negligible (Osman *et al.* 1990). Reasons for this include traditional land tenure patterns, traditional grazing rights, perception of legumes as part of the weed flora and overstocking. Implementation of the system would require, therefore, acceptance of new ideas by whole communities and not individual farmers. This will demand imaginative research and extension methods involving the decision makers at all stages.

Another opportunity for improving feed availability and quality in the dryer areas is the intercropping of shrubs with barley. Rehabilitation of the steppe by salt bush will be discussed later in this manuscript, but for land already ploughed the growing of saltbush (*Atriplex* spp.) in rows within barley fields provides complementary feed sources and soil protection against wind erosion (Jones and Arous 2000). In another study in northern Syria involving 7 farmers, Ghassali *et al.* (2011) reported a 25% increase of barley grain when barley was intercropped with rows of Mediterranean salt bush (*Atriplex halimus* L.).

Forage production (irrigated)

Rangeland degradation in the Arabian Peninsula (AP) has resulted in severe feed shortage over the years and obliged the farmers to grow Rhodes grass and alfalfa, both forages under high level of irrigation, 48 000 m^3 ha^{-1} per year (Peacock *et al.* 2003). Pumping of ground water for irrigation has resulted in lowering of water table in many countries of AP, increased salinity and in severe cases abandonment of farms (Sharaf 2001; Al-Senafy and Abraham 2004; Peacock *et al.* 2003). Freshwater is scarce and the consumption is high, which has put negative pressure on land resources, agricultural production and public health.

A joint research effort between the National Agriculture Research Systems (NARS) of the AP countries and ICARDA focused on identifying new forages that use less water in the production process. Collection missions for indigenous plant species were carried out in 6 AP countries (Bahrain, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen), where seeds of potential forages were collected (Osman 2005). Most of these species are being evaluated for their forage and seed production, feed quality and water use efficiency in the respective countries. A study was carried out in the central region of UAE on forage productivity, seed production and water use efficiency (WUE) for 2 years on 4 indigenous grasses: buffel grass (*Cenchrus ciliaris* L), *dakhna* (*Coelachyrum pierce* Benth.), *da'ay* (*Lasiurus scindicus* Henr.) and *tuman* (*Panicum turgidum* Forsk.) as well as one exotic species, Rhodes grass (*Chloris gayana* Kunth). Three irrigation treatments were used: R1 (1858-6758 m^3 ha^{-1} $year^{-1}$), R2 (929-3379 m^3 ha^{-1} $year^{-1}$) and R3 (464-1689 m^3 ha^{-1} $year^{-1}$). Buffel grass had the highest dry matter (DM) yield under all irrigation treatments, with an average of 14.6 and 15.1 t ha^{-1} in the two years, which was significantly higher than that for the other grasses, and *dakhna* had the lowest DM yield. The WUE of 0.7 and 0.8 kg DM m^{-3} in the two years for buffel grass was significantly greater than for the other grasses. Buffel grass also showed the highest increase in WUE in both years when the irrigation was reduced from treatment R1 to R3. Thus the desert grasses of the AP could be useful in reducing the use of scarce irrigation water provided that seed production can be increased (Osman *et al.* 2008).

Improved feed production on non-arable lands

Non-arable lands refer here to the Mediterranean grasslands, which constitute a large proportion of total land surface in west Asia (for example 30%-40% in Syria and Lebanon). These are communally owned, intensively grazed by sheep and goats and normally suffer from severe overgrazing and soil erosion. Nordblom and Thomson (1987) demonstrated that farmers with access to grasslands own more sheep and have more profitable livestock enterprises than farmers without access. Grasslands are heavily grazed in the spring (Cocks and Thomson 1988), and thus large amounts of supplementary feeding, such as barley grain, cereal and legume straw, green barley, crop by-products and sown forages are fed to small ruminants. Improved productivity of grasslands should reduce supplementation needs and increase carrying capacity. Soils in west Asia are diverse, but calcareous soils predominate. Calcium carbonate has pronounced influence on the chemistry of these soils and deficiencies of N and P are wide spread (Vlek *et al.* 1981; Cooper *et al.* 1987).

Grassland vegetation is predominantly annual legumes, though perennial grass and legume species are important in areas of high rainfall. More than 40 species of annual legumes were recorded on a typical grassland site in northern Syria; most of these were annual medics (*Medicago* spp.) and annual clovers (*Trifolium* spp.)

Phosphate fertilizers are widely used on grasslands in the Mediterranean-type climates of Australia and California, where the practice is linked with sowing of introduced medics and subterranean clover (*T. subterraneum*) as there are no native herbaceous legumes in Australia (Donald 1970) and the productivity of native legumes in California is low (Jones *et al.* 1970). In both Australia and California, the use of phosphate fertilizer results in sharp increase in livestock production (Russell 1960).

A study was conducted at Tel Hadya farm of ICARDA, 35 km south of Aleppo in north-west Syria. Tel Hadya has a mean annual rainfall of 342 mm and a growing season of 6.5 months. The climate is Mediterranean and rain falls from October to May. Summer is very hot and dry. The study was conducted on undisturbed native grassland. The predominantly annual vegetation includes a few low shrubs, perennial grasses and herbs. The soils are calcareous; the pH ranges between 7.8 and 8.4 and available P ($NaHCO_3$ extract) is 5.8 mg/kg. The slope is moderate and soil depth is variable (1-50 cm). The study comprised three rates of triple superphosphate, supplying 0 (referred to as P_0), 25 (P_{25}) and 60 (P_{60}) kg P_2O_5 ha^{-1} year^{-1} and two stocking rates: low (0.8 sheep ha^{-1} year^{-1}) and high (1.7 sheep ha^{-1} year^{-1}). Triple superphosphate was broadcast every year in September.

Ninety Awasi ewes were divided into groups of five, each consisting of ewes 2, 3, 4, 5, and 6 years old. Each group was permanently assigned to large (6.5 ha) or small (3.0 ha) plots, representing the low and high stocking rates, respectively, in each of the fertilizer treatments. In the fifth season, two more ewes (one 3 and one 4 years old) were added to each plot, raising the stocking rates to 1.1 and 2.3 sheep ha^{-1} year^{-1}, respectively. The experimental design was a randomized complete block with three replications. The total area of the experiment was 85.5 ha. The ewes grazed the plots for whole season, from early morning to sunset, being sheltered at night.

Soil P was estimated at the beginning of the experiment (before the fertilizer was applied) and in April each season thereafter. Organic matter was assessed at the beginning of the study and again 5 years later. Each season, herbage was sampled every 3-4 weeks from December until April. At each date, 30 samples per plot were collected along transects. Fifteen samples were taken from inside protective cages (60 x 60 x 40 cm) and 15 from matched sites outside; the cages were relocated after each sampling. Herbage production inside and outside the cages was used to calculate the total herbage yield. The first sample in the season from inside the cage represented total herbage yield for that sampling date. Total yield at the following sampling date was calculated by adding the increment in yield (difference in yield between inside the cage in the present sampling and outside the cage in the previous sampling) to the total yield of the previous sampling date. This was repeated for the rest of the season.

Seed yield was estimated in June each year. In 1985, 20 and 40 quadrat samples (50 x 50 cm) were taken from the high and low stocking rates, respectively, taking all vegetation and the top one centimeter of soil. In the following years, 15 quadrats (20 x 20 cm) per plot were used. Seeds were separated from the soil and from threshed vegetation of each sample and were cleaned, identified, counted and weighed.

***Changes in phosphorus and organic matter contents**:* Available P was less than 10 mg kg^{-1} in all treatments when the experiment began in 1984, but significantly ($P<0.01$) increased as a result of fertilizer (Table 1). There was steady decline in available P in the P_0 treatment. Soil organic matter increased significantly as a result of phosphate application. Five years after the experiment began, the organic matter content at P_{25} and P_{60} was 12% and 20% higher, respectively, than at the beginning of the experiment, compared with only 6% increase at P_0.

Table 1: Available phosphorus in the soil (mg kg^{-1}) before phosphate application (1984) and at three rates of phosphate in each of five seasons at Tel Hadya, northern Syria

Phosphate rate* (kg P_2O_5 ha^{-1})				
Season	0	25	60	S.E.
1984	7.9	6.6	7.2	1.34
1984/85	9.5	13.6	34.3	3.78
1985/86	8.1	12.3	17.9	1.20
1986/87	5.0	9.4	16.2	1.25
1987/88	4.6	24.4	58.1	3.53
1988/89	7.1	19.0	41.8	3.81

*Each value is an average of two stocking rates. There was no significant stocking rate x phosphate interaction

***Total herbage yield and legume component**:* Significant differences were recorded due to P application in both total herbage yield and in legume component of the pasture throughout the five seasons (Table 2). Highest herbage yield was recorded in the spring each season, which reflects the phosphate application and the rainfall. Differences between P_{25} and P_{60} were significant in one season (1987/88) when the rainfall was nearly 500 mm. Herbage yield of legume showed similar pattern to the total herbage production; however there were more sharp differences in favor of phosphate application over the control (Table 3).

Table 2: Total herbage yield (t ha^{-1}) during 5 seasons in relation to phosphate application at Tel Hadya, northern Syria

Season	Rainfall (mm)	Phosphate rate (kg P2O5 ha-1)			S.E.
		0	25	60	
1984/85	369.5	0.8	1.1	1.1	0.08
1985/86	287.5	1.0	1.4	1.4	0.11
1986/87	340.3	1.7	2.1	2.4	0.15
1987/88	496.6	2.2	3.9	4.5	0.23
1988/89	219.5	0.9	1.3	1.7	0.08

Table 3: Annual legume (%) of the whole above ground biomass as related to phosphate in 5 years at Tel Hadya, northern Syria

Phosphate rate ($kg\ P_2O_5\ ha^{-1}$)		Season				
		1984/85	1985/86	1986/87	1987/88	1988/89
0	20		5	16	43	17
25	27		14	32	63	34
60	30		15	37	64	46
S.E.	3.8		2.1	3.0	2.5	3.4

Rain use efficiency (RUE): There was a strong tendency of rain use efficiency (yield of dry matter/ unit area per unit of rainfall) to increase with time, especially at high rates of fertilizer. By the fourth season of the study, rain use was nearly twice as efficient at P_{60} compared with P_0, and this difference was maintained in the driest year, 1988/89 (Table 4).

Table 4: Rain use efficiency (kg DM ha-1 mm-1 of rainfall) on grazing land in relation to 3 levels of phosphate during 5 seasons at Tel Hadya, northern Syria

Season	Rainfall (mm)	Phosphate rate ($kg\ P_2O_5\ ha^{-1}$)			S.E.
		0	25	60	
1984/85	369.5	2.03	3.01	2.70	0.196
1985/86	287.5	3.37	4.27	4.18	0.262
1986/87	340.3	4.59	5.82	6.69	0.397
1987/88	496.6	4.37	7.64	9.15	0.423
1988/89	219.5	3.89	5.29	7.52	0.332

Seed production*:* The number and mass of legume seeds recorded over the five seasons at P_{60} were, respectively, 2-6 and 2-5 times the amounts at P_0 (Table 5). Seed size declined throughout the study. In 1984/85 to 1988/89, average seed weight was 1.20, 1.47, 1.03, 0.86 and 0.73 mg, respectively. There was no consistent effect associated with P; the change in the seed size was associated with the increasing dominance of the small-seeded species (*Trifolium tomentosum* and *T. campestre*).

Table 5: Mass of legume seeds in the top 1 cm of soil (g m-2) and number of seeds m-2 at three rates of phosphate (mean of two stocking rates) in each of 5 seasons at Tel Hadya, northern Syria

Season	Phosphate rate ($kg\ P_2O_5\ ha^{-1}$)			S.E.
	0	25	60	
Seed mass				
1984/85	2.9	3.7	4.6	0.64
1985/86	1.4	2.2	4.2	0.59
1986/87	2.1	6.8	9.9	1.19
1987/88	10.3	25.4	27.6	2.01
1988/89	2.7	12.1	17.4	1.23
Seed number				
1984/85	2108	3112	3987	448.3
1985/86	1586	2063	3379	442.6
1986/87	2858	8786	11704	1370.1
1987/88	13804	34932	34227	2682.5
1988/89	4327	18637	24129	1867.7

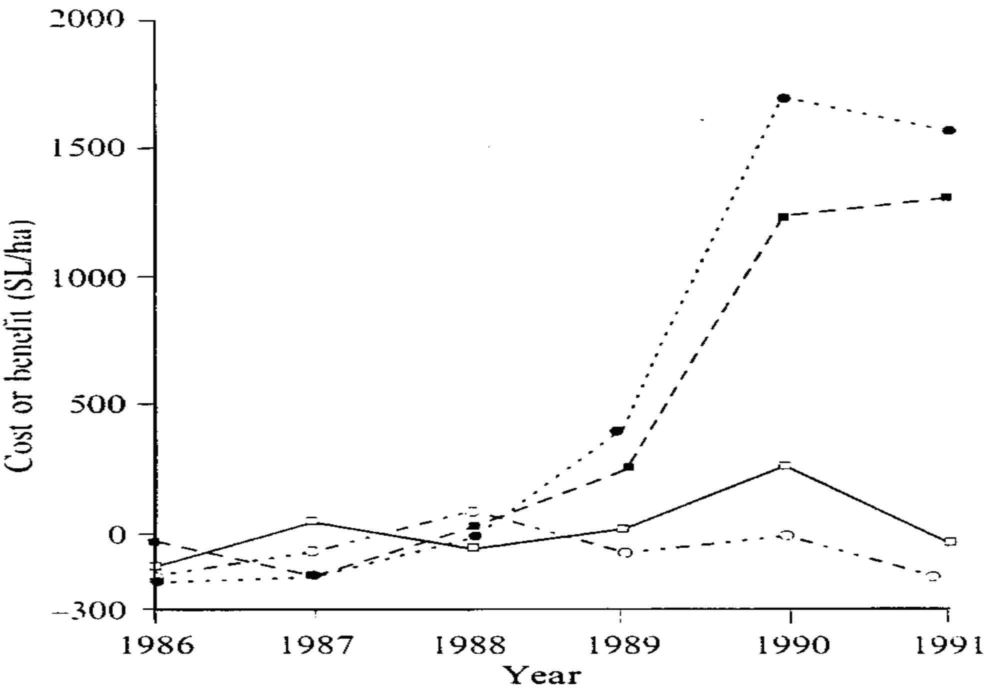

Figure 1: The cost or benefit (Syrian pounds ha^{-1}) obtained from top-dressing grassland with 25 kg P_2O_5 ha^{-1}at low (□) and high (■) or with 60 kg P_2O_5 ha^{-1} at low (○) and high (●) stocking rates compared with no-dressing controls. The costs/ benefits were calculated from the savings obtained from reduced feed costs and from extra milk production.

Livestock production: Live weight, milk yield, wool production and supplementary feeding were monitored for six seasons (1985/86 to 1990/91). The results showed that phosphate fertilizer improved sheep productivity. Live weights were higher in five out of six years, significantly so in the last three. Milk production was also higher in phosphate treated plots and the need for supplementary feeding was reduced, especially in the last three years, when rainfall was below average. These results suggest that stocking rates can be significantly increased by annual application of small amounts of superphosphate, and doing so is profitable (Fig.1).

Improved feed production on rangelands

For decades, rangelands in North Africa and West and Central Asia had suffered overgrazing, and many areas were severely degraded (Emberger 1956; Cocks *et al.* 1986; Osman and Shalla 1994; Benchaabane 2000). Out of 18.5 million ha (the total area of Syria), 10.2 millions are considered rangeland, which receive no more than 200 mm of rainfall and is unsuitable for cultivation, but support native pasture which is used by increasing number of livestock (sheep in Syria were estimated at 13.3 million heads in 1988 compared with 4.3 million in 1963). It is estimated that 75% of the sheep population in Syria use the rangeland during part of the year (Asaad 1992). Rangelands in Syria, originally supporting woodland and shrub vegetation, now comprise

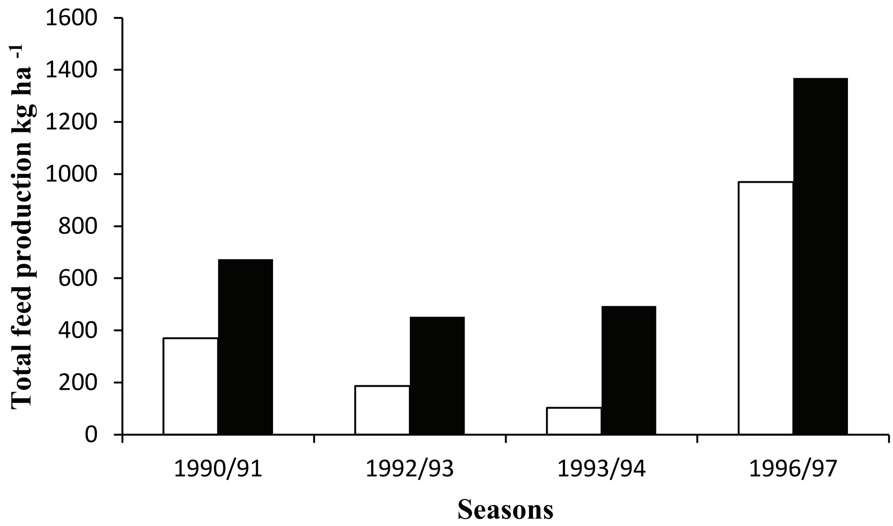

Figure 2: Total feed production (kg ha^{-1}) of herbaceous plus grazable portions of shrubs during the spring of four seasons on native unimproved pasture (☐) and on shrub-seeded pasture (■) average of three stocking rates, at Maragha, northern Syria.

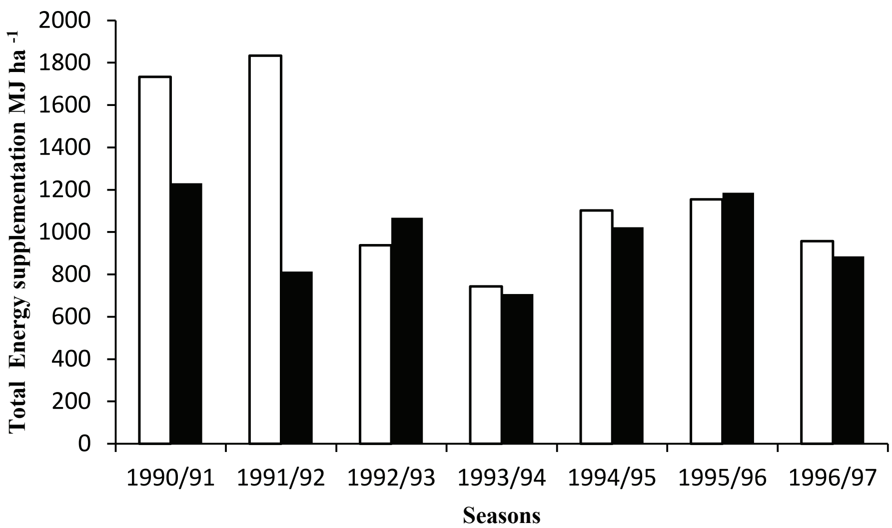

Figure.3: Total energy supplementation MJ ha^{-1} during seven seasons on native unimproved pasture (☐) and on shrub-seeded pasture (■) as affected by three stocking rates at Maragha, northern Syria.

annuals, mainly low growing grasses and herbs and occasionally small populations of legumes. They produce an average of 400 kg dry matter ha^{-1} year^{-1} (Cocks *et al.*1986) in contrast to the expected forage yield of 1-2 t ha^{-1} year^{-1} of Mediterranean rangelands (Le Houe´rou and Hoste 1977; Gintzburger 1986). Degradation of vegetation such as this is often accompanied by severe soil erosion, especially wind erosion. It was also reflected in an increased use of concentrates to animals (Masri 1991). Razzouk (1998) indicated that 46% of the cooperative members in Syrian

Table 6: October to May Monthly rainfall and total annual rainfall (mm) at Maragha Station from 1990/91 to 1996/97

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1990/91	4	11	15	40	16	111	3	15	215
1991/92	8	12	15	50	75	3	0	22	185
1992/93	0	47	18	41	48	12	0	44	210
1993/94	0	17	18	27	32	13	18	9	134
1994/95	12	79	46	23	14	15	27	0	186
1995/96	0	25	21	65	34	81	19	8	253
1996/97	11	14	50	64	56	29	30	0	254

Long term average annual rainfall for Maragha Station is 196 mm

Table 7: The net benefits [a] in US \$ ha^{-1} [b] of the shrub-sown pasture over native pasture at three stocking rates during seven seasons.

Season	Stocking rate			Average
	Low	Medium	High	
1990/91	9.05	20.29	25.27	18.20
1991/92	16.07	15.31	31.47	20.95
1992/93	-2.91	2.95	-7.51	-2.49
1993/94	-5.51	8.15	16.15	6.26
1994/95	-2.33	2.03	1.85	0.52
1995/96	0.53	-1.55	-2.67	-1.23
1996/97	0.75	2.89	12.11	5.25
Total	15.65	50.07	76.67	47.46

[a] Total benefits minus the cost of establishing shrubs (4 US \$ averaged over the seven seasons); [b] The benefits were calculated from the savings obtained from reduced feed costs and from extra milk and lamb sales at weaning (negative values indicate better performance on native pasture)

steppe use concentrate for 3-5 months $year^{-1}$ while 41% use concentrates for 6-8 months and 9% use the concentrates for 9-12 months.

Planting of shrubs is known to reverse the degradation of rangeland. These shrubs can play an important role in animal production; being a source of protein and other nutrients, they provide green feed for animals at times of low nutritional value of grass and forbs, and provide a drought reserve when other forage sources are in short supply (Pengelly *et al.* 2003). An extensive program of range rehabilitation was started in Syria in 1986. At first, the activity was focused on use of seedlings of exotic species: *Atriplex nummularia* L. and *A. canescens* L. (Draz 1978). Later work has shown that the native shrubs *Atriplex halimus* L. and *Salsola vermiculata* L. perform even better than the exotic species (Asaad 1992). The latter can be established from direct seeding and, more importantly, they are self-reseeding (Osman and Shalla 1994).

Both native shrubs are fairly palatable to highly palatable to goats, sheep and camels (Le Houe´rou 1994; Murad 2000; Tadros 2000). Over 300 000 ha of rangeland in Syria have been improved by growing shrubs, approximately 50 000 ha of which were established by direct seeding. Although the cost of direct seeding is one-tenth that of shrub transplanting (Osman and Shalla 1994), the success of direct seeding is dependent on other factors, such as seed quality (germination) and land preparation for harvesting rainwater. Seed germination of *S. vermiculata* and *A. halimus* is improved significantly by removing fruiting bracts from fruits (utricles) and when seeds are stored under cold temperatures (Osman and Ghassali 1997).

A joint field study was started in 1989/90 at Maragha (120 km east of Aleppo, northwest Syria, annual rainfall 196 mm) by the International Center for Agricultural Research in the Dry Areas (ICARDA), the Syrian Ministry of Agriculture and the Arab Center for Studies of the Arid Zones and Dry Lands (ACSAD). The objectives were to determine the productivity of rangelands improved by sowing edible shrubs, to monitor the effects of three stocking rates on biomass production and on sustainability of livestock production and to measure the economic return. Full details of the study were reported by Osman *et al.* 2006. The main highlights of the study can be summarized as follows:

The study was carried for seven seasons (1990/91-1996/97) on 108 ha improved with seeding of *S. vermiculata* and *A. halimus*, and 108 ha of native unimproved pasture. On each pasture there were 3 stocking rates: one sheep per 2.25 ha, one sheep per 1.5 ha and one sheep per 0.75 ha, on a year round basis. There were 8 animals per plot of 18, 12 and 6 ha, representing low, medium and high stocking rates, respectively. The treatments were replicated three times, and the paddocks were fenced. The animals were introduced to the experimental plots in February 1990 and grazed the plots for the whole year from morning to sunset (sheltered at night). Each year, the oldest two ewes in each plot were replaced (the age groups in each plot: 3, 4, 5 and 6 years i.e. two animals each). Sick and barren ewes were also replaced. Water was provided in the pasture at all times and at night in the pens. Mating started in the first week of July and ewes from replications of the same treatment were grouped together and one ram was kept with the group for 6-8 weeks. Lambs in excess of one per ewe were removed at birth and managed separately, so that all experimental ewes suckled one single lamb. Lambs stayed with their mothers on pastures for 63 days at which time they were weaned, weighed and sold.

Supplementary feeding, when necessary, was formulated to supply the nutritional requirements for energy and protein as affected by body weight and animal production phase (i.e. pregnancy, lactation, milking, dry ewes and mating), taking into consideration the feed quality and availability on the pasture.

Range productivity in this study was not only affected by total rainfall, but also by rainfall distribution. Pasture productivity of native pasture ranged from 103 kg ha^{-1} when rainfall was 134 mm (1993/94) to 969 kg ha^{-1} when it was 254 mm (1996/97). Corresponding values for the shrub-sown pasture were 494 kg ha^{-1} and 1369 kg ha^{-1} (Fig. 2). A good example of the influence of the rainfall distribution is 1990/91 where the total rainfall was 215 mm (only 5 mm higher than in 1992/93). However, over 50% of the rain (111 mm) was received in March in 1990/91 compared with (12 mm) in March of 1992/93 (Table 6). Such pattern of distribution may explain the big difference in native pasture productivity in the two seasons (370 and 187 kg ha^{-1}, respectively). The rain-use efficiency (kg DM ha^{-1} mm^{-1} rainfall) for the two seasons was 0.77 and 3.81, for the native pasture and 3.69 and 5.39 for the shrub-seeded pasture. It seems therefore, growing shrubs in the steppe would result in a similar effect of adding phosphorus to grassland where rain-use efficiency was improved significantly (Osman *et al.* 1991).

The mean energy supplementation was greater with native range than with shrub-sown pasture in five out of the seven seasons (Fig.3). The feed availability (shortage) in this study, as in other studies, was related to the amount of supplementary feed (Arthun *et al.* 1992).

The average net benefits in the present study were positive for the shrub-sown pasture during five out of the seven seasons, with the biggest incomes being generated in the first two years of the study. The total net benefits increased with stocking rate. The accumulated total benefits during the study period were about 16, 50 and 77 US \$ ha^{-1} at low, medium and high stocking rates, respectively (Table 7).

The results suggest good benefits to the livestock owners, who are expected to pay fees for renting these pastures especially during drought years. Indeed, this was the case in 1994/95, which followed a drought year (Table 6), when ten groups of herders brought their flocks (18 000 head) to Maragha shrub reserve and paid approximately 2.5 US \$ to graze three animals on a hectare of land for one month. One of the shepherds commented, "if my sheep were out on the poor range (the native pasture), I would have to supplement them with about 300 kg of feed per day". The estimated supplementary feed for his flock (200-300 sheep) would cost about 1150 US \$ a month. Therefore, the outlay of about 210 \$ to graze the sheep on fodder shrubs for the month is indeed economically appealing (80% reduction in the cost of supplementary feeding).

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Potential of salt-tolerant forage grasses as animal feeds in salt affected lands in Sinai, Egypt

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Abstract

Natural vegetation, the principle feed resource for livestock, in South Sinai has deteriorated and cannot cover their nutritional requirements. Groundwater and soil resources in the region are greatly affected by salinity. Introduction of biosaline agriculture production system could be an effective way to overcome the limitation of raising salinity levels on agricultural production. This study aimed to evaluate the effects of irrigation water salinity levels and irrigation systems on some growth traits, crop yield and nutritive value of three salt - tolerant grass species. Pearl millet *(Pennisetum glaucum,*L. R. Br.), Sudan grass (*Sorghum sudanense)* and Sorghum (*Sorghum bicolor*, L. Moench) were cultivated in salt affected soil of South Sinai Research Station Farm. The grasses were irrigated with two levels of saline groundwater: medium salinity (> 4000 ppm total salts) and high salinity (> 7000 ppm total salts) using drip irrigation system (DIS) and gated pipes irrigation system (GPIS). Results indicated that pearl millet recorded the highest values of most of growth traits and was superior in both fresh and dry weight, leaf area and biological yield in comparison with the other grasses. DIS was better than GPIS both in terms of dry weight and biological yields which increased by 25 and 18%, respectively. The yield was lower at high salinity than medium salinity level of irrigation water. The three grasses are nutritious for small ruminants as they contained acceptable concentrations of crude protein to cover their protein requirements. The grasses have great potential for feeding animals during summer and autumn seasons when feed shortage is common. In conclusion, cultivation of these salt-tolerant grasses under moderate soil and irrigation water salinity is biologically and economically feasible and can help poor farmers in South Sinai to overcome the shortages of forages and use the marginal land and water resources in a sustainable and productive way.

Introduction

Livestock production is the main activity of most of the Bedouins in Sinai Peninsula of Egypt. It is considered one of the main sources of their income. The natural vegetation of this region is based, commonly, on halophytes and salt tolerant shrubs and semi- shrubs which represent the principle animal feed resource (El Shaer 2010). The vegetation cover is seasonal and drastically varies depending on rainfall. There is chronic shortage of forage in the area due to several environmental and management factors (El Shaer 1981, 2004). The yield of this vegetation as animal feed material does not cover the annual nutritional requirements. Wadi Suder region, as well as other regions in South Sinai, is characterized by saline soils and various levels of salinity of the underground water (Wassif *et al.* 1983). Introduction of biosaline agriculture production systems has proved to be an effective way to overcome the limitation of rising salinity levels on agricultural production (Anon. 2006). Desert Research Center (DRC) of Egypt and the International Center for Biosaline Agriculture (ICBA) of UAE developed a collaborative project to introduce and evaluate several conventional and non-conventional salt-tolerant forage production systems that are suitable for salinity levels up to 25 dS/m. This study was carried out to evaluate the effects of irrigation water salinity and irrigation systems on growth traits, yield and nutritive value of three summer salt-tolerant forage grass species.

Materials and methods

The study was conducted at the South Sinai Research Station, Wadi Sudr region, South Sinai Governorate, Egypt, during April to November 2008. Wadi Sudr is an arid region, located 200 Km south east of Cairo, where rainfall or fresh water is very limited. The brackish saline water pumped from wells is the sole source of irrigation. So, soil and irrigation water salinity is the major problem in this area. The region is characterized by extremely arid climate, where the annual rainfall is about 16 mm/year. The relative humidity is generally low (45 to 55 %). The air temperature is mild: mean maximum is 35 ^{o}C, minimum is 18^{o}C; and annual is 22 ^{o} C.

Three perennial salt tolerant grasses: Sudan grass *(Sorghum sudanonse)*, pearl millet grass (*Pennisetum americanum*) and sorghum (*Sorghum bicolor)* were evaluated with two levels of underground water salinity and two methods of irrigation in a split-plot design. Underground water salinity levels were medium (MS, 4000 ppm) and high (HS, 7000 ppm total salts). Irrigation methods were drip (DIS) and gated pipes (GPIS). Organic manure, at a rate 20 m^3/fed, and 30 kg P_2O_5/fed were incorporated in the soil before sowing. In addition, 45 kg N/fed and 15 kg K_2O/fed were given.

Regular composite samples of irrigation water from each underground well and soil samples were taken for analysis. Growth and yield characters were determined for each grass species: plant height (cm), number of leaves/plant, fresh weight (g), dry weight (g), leaf area (cm^2), fodder yield (kg/m^2). The crop forage production, as fresh or in terms of dry matter (DM), total digestible nutrients (TDN) and digestible crude protein (DCP) yield per feddan (1fed=0.4 ha were also determined. Data were subjected to statistical analysis according to Steel and Torrie (1980). The mean values were compared at 0.05 level of probability by Duncan's multiple range test of mean separation (Duncan 1955).

Results and discussion

Chemical analysis of soil and irrigation water:

The soil of Ras Sudr area was characterized (Table 1) as medium to low quality soil for agriculture. The soil limitations include coarse texture, soil salinity, high calcium carbonate, rock fragments, and low soil fertility. The results are in close agreement with those reported by many investigators who conducted their studies under similar conditions in the Wadi Suder region (Youssef *et al.* 2009 and Anon. 2012). The main water resource for agriculture sector in Ras Sudr area is ground water from quaternary aquifer. The depth to water is less than 100 m where salinity varies from 400 to 9000 ppm. Chemical analysis of ground water at the Research

Farm used for irrigation is summarized in Table 2. Salinity concentration (EC) in high salinity (HS) irrigation water was almost double that of the medium salinity (MS) irrigation water; and concentrations of most of the mineral ions such as Na, K and Cl were higher in HS than in MS.

Table 1: Chemical properties of the soil at the experimental site

Soil depth (cm)	EC (mmhos/ cm)	pH	Soluble cations (meq/L.)				Soluble anions (meq/L.)		
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0 – 50	12.5	7.3	22.5	13.0	66.0	0.45	19.2	61.0	12.9
50 – 100	11.3	7.5	21.5	11.4	65.0	0.46	21.3	59.0	14.8

Table 2: Averages of chemical analysis of ground water used for irrigation

Attributes	Medium salinity water	High salinity water
pH	7.67	7.39
EC (ds/m)	7.53	13.9
Na^{+} (mg/100 mg)	30.3	40.2
Ca^{++} (mg/100 mg)	20.6	23.94
Mg^{++} (mg/100 mg)	11.9	16.6
K^{+} (mg/100 mg)	0.99	2.88
Cl^{-} (mg/100 mg)	29.1	42.43
HCO_3^{-} (mg/100 mg)	3.28	3.28
SO_4^{--} (mg/100 mg)	20.2	24.3

Effect of irrigation water salinity levels and irrigation systems on growth traits: Data on some growth traits of the three grasses as affected by the treatments are summarized in Table 3. The results indicated that all growth traits of the grasses species were influenced significantly (P0.05<) by irrigation system and salinity levels of irrigation water. DIS recorded higher values of all growth traits as compared to GPIS. DIS improved dry weight and biological yields by 25 and 18%, respectively, over GPIS , on overall average basis.

Medium salinity water improved all plant growth traits for the three grasses as compared to high salinity. Similar trends were recorded by many investigators using different varieties of sorghum and pearl millet (El Shaer *et al.* 1987, 1992; Saida 1994; Abd- El-Hamid 1998; Anon. 2012).

Data in Table 4 revealed that all growth traits were significantly (P0.05<) affected by the plant species regardless the irrigation systems and salinity levels of irrigation water. On overall average basis, pearl millet showed the highest (P0.05<) number of leaves/ plant, fresh and dry weight, leaf area and biological yield. Although plant height of pearl millet was 17 and 10% lesser than of sorghum and Sudan grass, respectively, its biological yield was respectively 24 and 32% higher. Such findings are in close agreement with those reported for sorghum and Sudan grasses by Saida (1994) and Moawd (1998) and on pearl millet by Ashraf and Idrees (1992), Bakht *et al.* (2000), and Ali *et al.* (2006).

Table 3: Effect of irrigation system and irrigation water salinity on growth traits of the three grass species

Grass species	Salinity levels (ppm)	Irrigation systems*	Plant height (cm)	No. of leaves/ plant	Fresh weight (g)	Dry weight (g)	Leaf area (cm)	Biological yield (g)
Pearl millet	>4000	DIS	170 a	17 a	65.41 a	19.30 a	85.5 a	11.50 a
		GPIS	130 b	11 b	45.50 b	14.00 b	77.5 b	9.00 b
	>7000	DIS	115 a	14 a	40.60 a	12.90 a	66.4 a	8.89 a
		GPIS	80 b	10 b	30.71 b	10.14 b	60.4 b	6.80 b
Sorghum	>4000	DIS	140 a	13 a	50.05 a	15.01 a	85.0 a	8.15 a
		GPIS	90 b	10 b	31.00 b	10.41 b	77.9 b	6.09 b
	>7000	DIS	110 a	11 a	44.17 a	13.14 a	64.1 a	7.15 a
		GPIS	80 b	8 b	28.00 b	10.00 b	47.9 b	6.10 b
Sudan grass	>4000	DIS	180 a	16 a	38.14 a	12.31 a	60.4 a	6.41 a
		GPIS	140 b	10 b	24.00 b	9.00 b	55.5 b	5.84 b
	>7000	DIS	139 a	12 a	30.71 a	10.87 a	50.1 a	6.51 a
		GPIS	91 b	10 b	25.00 b	9.00 b	39.9 b	5.81 b

* Drip irrigation system : DIS *Gated pipes irrigation system :GPIS; values with different letters differ at 5%

Table 4: Growth traits of the grass species (overall average)

Grass species	Plant height (cm)	No. of leaves/ plant	Fresh weight (g)	Dry weight (g)	Leaf area (cm)	Biological yield (g)
Pearl millet	123.8c	13a	45.6a	14.1a	72.4a	9.05a
Sorghum	150a	10.5c	38.3b	12.1b	68.7ab	6.87b
Sudan grass	137.5b	12b	29.5c	10.3bc	51.5c	6.14b

Values with different letters differ at 5%

Nutrient yield:

Studies on intake and nutritive value of the studied grasses using sheep were conducted by one of the authors. The results are reported in Table 5. Concentration of crude protein (CP), crude firber (CF), ether extracts(EE), and neutral detergent fiber (NDF), sodium (Na), potassium (K) were comparable and not influenced by salinity level of irrigation water. The grasses appeared to be nutritious for small ruminants as they contained enough CP content to cover protein requirements of animals. They had low concentrations of ADF and ADL as compared to traditional good quality roughages (Kearl 1982). Comparable values were obtained by several investigators using pearl millet (Messman *et al.*; 1992 and Fahmy 2001), sorghum (Gabra 1984) and Sudan grass (Moawd 1998). Regardless the plant species, plants irrigated with HS contained higher CP and ADL, ash, and the trace elements (Cu, Zn and Co) contents in comparison with those irrigated with MS water.

Data in Table 6 showed that the crop yield, as fresh weight or in terms of DM, TDN or DCP, of the three grasses irrigated with MS water was greater than that recorded with HS water. Sorghum irrigated using MS water recorded the highest fresh biomass production and DM, CP, TDN and DCP yields (9519, 3379, 399, 2031 and 282 kg/ fed, respectively). On the other hands, pearl millet irrigated with HS water attained the greatest production of fresh biomass, DM, CP, TDN and DCP (6881, 1376, 187, 759 and 137 kg/ acre, respectively).

Table 5: Chemical composition, fiber constituents and mineral contents of the experimental grasses (%, on Dry matter basis) irrigated with medium and high saline water

	Medium salinity			High salinity		
Attributes	**Sudan Grass**	**Pearl millet**	**Sorghum**	**Sudan Grass**	**Pearl millet**	**Sorghum**
Chemical composition:						
DM	91.1	91.7	90.4	88.2	89.1	88.5
Ash	10.4	14.9	10.9	12.6	14.4	14.5
CP	12.3	13.4	11.8	13.6	13.6	13.2
CF	24.1	25.8	24.9	24.3	26.1	24.9
EE	2.1	2.8	1.65	1.85	1.49	2.86
NFE	51.1	43.1	50.75	47.65	44.41	44.56
Fiber constituents:						
NDF	76.8	81.2	77.0	73.1	82.4	76.6
ADF	32.8	32.3	37.6	29.7	33.5	28.3
ADL	3.13	2.32	2.58	4.10	4.90	3.20
Hemicellulose	44.0	48.9	39.4	43.4	48.9	48.3
Cellulose	29.67	29.98	35.02	25.6	28.6	25.1
Mineral contents :						
Na	2.1	1.8	1.7	2.1	2.1	1.9
K	3.7	3.0	2.5	3.8	3.1	2.5
Cu, ppm	81	85	88	91	105	102
ZN, ppm	78	53	48	81	80	80
CO, pmm	12	11	14	15	18	16

(Cited from Fahmy et al. 2010)

Table 6: Average crop yields of the cultivated salt tolerant grasses (kg/ acre)

Items	**Medium salinity (MS)**			**High salinity (HS)**		
	Sudan grass	**Pearl millet**	**Sorghum**	**Sudan grass**	**Pearl millet**	**Sorghum**
Green fodder yield	7320	8051	9519	3899	6881	4368
Dry matter yield	2013	1522	3379	1357	1376	1057
Crude protein yield	247	204	399	185	187	139
TDN yield	1125	866	2031	725	759	561
DCP yield	156	137	282	136	137	100

It can be noticed that the per feddan production of these nutrients of such grasses could cover the maintenance and lactation requirements of 55 and 24 sheep, respectively for 90 days when these animals are fed on sorghum grass irrigated with MS water. Sudan grass or pear millet irrigated with HS water would cover the maintenance and lactation requirements of 20 and 9 animals, respectively. These results indicated that the tested salt-tolerant grass species showed great potential as good quality animal feed under saline conditions of the region, particularly during summer and autumn seasons when traditional feed materials are not available and natural rangelands are very poor (Anon. 2006 and El Shaer 2010). Such findings support the earlier findings by some workers using similar grasses species grown in salt affected soils (Saida 1994; Moawd 1998).

Conclusion

It is concluded that under saline conditions of the region, the three salt -tolerant grasses species have great potential for feeding animals, because of their yield and nutritive value, particularly during summer and autumn seasons when feed shortage is common. Cultivation of such conventional salt-tolerant forage grasses under moderate soil and irrigation water salinity conditions is biologically and economically feasible and can help poor farmers in Sinai Peninsula to overcome the shortage of forages and use the marginal land and water resources in a sustainable and productive way. The achievements of this study can be adapted and transferred to other similar saline agricultural systems in Egypt.

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Evapotranspiration and its source components change under experimental warming in alpine meadow ecosystem of Qinghai-Tibet Plateau

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Abstract

Climatic warming is considered as one major driving force for alpine meadow degradation in the Qinghai-Tibet Plateau as warming affects soil moisture through accelerating the evapotranspiration. Partitioning evapotranspiration (*ET)* into soil evaporation (E_a) and plant transpiration (T_r) is important for understanding soil moisture change mechanism, and their differential responses to climatic warming. A field experiment was conducted to investigate the climatic warming effects (W1: 130 W m^{-2} and W2: 150 W m^{-2} additional radiation) on soil moisture, *ET* and its components (i.e. E_a and T_r) of alpine meadow in the Qinghai-Tibet Plateau. *ET* was calculated using energy balance model and soil moisture correction function. Warm-rainy season E_a was modeled by multiple linear regession with latent heat, soil temperature at 20 cm and T_r was quantified as the difference between *ET* and E_a. Warming significantly decreased soil moisture in shallow layers (10 and 20 cm depth). Annual *ET* and its components were significantly stimulated by warming. Annual *ET* increased by 92.65 and 89.18 mm in W1 and W2 treatments. E_a was 51.7-57.8% of the *ET* and decreased with warming level. Annual E_a increased by 29.12 and 33.37 mm, and T_r increased by 63.53 and 55.81 mm in W1 and W2 treatments, respectively. The results suggest that warming induced T_r increase accounted for most *ET* change and the shallow soil layer moisture decrease in growing season of the alpine meadow in Qinghai-Tibet Plateau.

1. Introduction

Alpine ecosystems degradation has been accelerated by climatic warming in some sensitive regions (Jorgenson *et al.* 2001; McGuire *et al.* 2003; Wang *et al.* 2007). The Qinghai-Tibet Plateau (QTP) is experiencing “much greater than average” increase in surface temperature based on the predictions of coupled climate-carbon cycle models (IPCC 2007) and observed data from meteorological stations (Liu and Chen 2000). In the late 20th century, alpine meadow had degraded in the QTP due to change in water balance that is affected by permafrost degradation and surface layer drying under warming climate (Harris 2010; Wang and Cheng 2001; Wang *et al.* 2007; Xie *et al.* 2010; Xue *et al.* 2009; Zhou *et al.* 2005).

Evapotranspiraton (*ET*), composed of plant transpiration (T_r) and soil evapotration (E_a), is an important land surface process in regulating ecosystem water balance (Jung *et al.* 2010). *ET* is sensitive to air temperature, relative humidity and short-wave radiation (Gong *et al.* 2006), stomatal conductance (Serrat-Capdevila *et al.* 2011), soil moisture (Jung *et al.* 2010), plant phenology (Raddatz and Shaykewich, 1998; Zavaleta *et al.* 2003) and locations (Calanca *et al.* 2006), which resulted in different *ET* responses to climatic warming. Generally, *ET* is stimulated under warming climate as temperature and atmospheric vapor pressure deficit increases (Beniston 2003; Calanca *et al.* 2006; Gong *et al.* 2006; Goyal 2004; Lawrence *et al.* 2007a). The corresponding increase in surface resistance could however cancel out the effects of promoted atmospheric evaporative demand, and therefore keep *ET* unchanged (Serrat-Capdevila *et al.* 2011). Under warming climate, soil moisture would decrease. The decreased water availability, observed in many modeling analysis (Albertson and Kiely 2001; Bell *et al.* 2010) and field experiments (Klein *et al.* 2005; Niu *et al.* 2008; Wan *et al.* 2002) could offset positive effects of warming on *ET* or even decline *ET* (Jung *et al.*, 2010).

Current land surface schemes and few available observations indicate that T_r is the dominant component of *ET* on the global scale, followed by E_a (Dirmeyer *et al.*, 2005; Lopez C *et al.*, 2007). However, results of Community Land Model version 3 (CLM3) demonstrated E_a far outweighs T_r (Lawrence *et al.,* 2007b). Observational study also showed that T_r only accounts for 22% *ET* in sparse grassland at the edge of Eurasian cryosphere (Zhang *et al.,* 2005). E_a and T_r were projected to increase under warming climate (Misson *et al.*, 2002; Wetherald and Manabe, 2002). Higher temperature and the corresponding increase in water vapor deficit have two contrasting effects on T_r. Air temperature increases driving force for water diffusion out of leaves while increase in water vapor deficit decreases canopy conductance. The magnitude of those responses to warming is species-dependent (Misson *et al.,* 2002). On an annual base, T_r change under warming climate was the result of phenology change. For example, advancement of canopy senescence in arctic and alpine ecosystem under warming climate led to T_r decline, and therefore *ET* reduction, since T_r contributes most to *ET* (Raddatz and Shaykewich 1998; Zavaleta *et al.* 2003).

Qinghai-Tibet Plateau is one of the most sensitive regions to climate change (Liu and Chen 2000). Evapotranspiration and its components responses to warming climate are important to understand the mechanism of soil moisture change, which influences the development of permafrost and alpine ecosystem. The objectives of this study were: (1) to evaluate T_r and E_a contribution to *ET* and (2) to investigate warming effects on soil water content, T_r , E_a and *ET* of the alpine meadow ecosystem under warming climate conditions in the Qinghai-Tibet Plateau.

2. Materials and methods

2.1 Site description

The warming manipulation experimental site was situated in the Yangtze River source region and inland Qinghai-Tibet Plateau near the Beilu River research station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences (92°56′E, 34°49′N), with an altitude of 4635 m above sea level (ASL) and typical alpine climate. Basic environmental conditions are as follows: mean annual air temperature -3.8^{0}C with the mean annual maximum temperature of 19.2 ^{0}C and the mean annual minimum temperature of -27.9 ^{0}C ; mean annual precipitation 290.9 mm with over 95% falling during warm growing season (from May to October); potential mean annual evaporation 1316.9 mm; mean annual relative humidity 57% and mean annual wind velocity 4.1m s^{-1} (Lu *et al.* 2006). Our study site is a summer-grazed range, dominated by alpine meadow vegetations such as *Kobresia capillifolia*, *Kobresia pygmaea*, *Carex moorcroftii*., with mean plant height of 5 cm. The soil development is weak and belongs to Mattic Cryic Cambisols (Alpine meadow soil, as Cambisols in FAO/UNESCO taxonomy) with a mattic epipedon in approximately 0-10cm depth and organic-rich layer in 20-30 cm depth (Wang *et al.* 2007). Permafrost thickness observed near our experimental site ranges from 60 to

200 m with 2.0-3.2 m depth of active layer (Lu *et al.* 2006; Pang *et al.* 2009) and the active layer thickness has increased by the rate of 3.1 cm y^{-1}(Wu and Liu 2004) due to warming in this region.

2.2 Experimental design

Our experiment uses a random block design. Five blocks with one control and two warming plots in each block were installed in June, 2010. Plots size is 2 × 2 m. Within each block, plots were selected for similarity of topography, soil texture, aboveground biomass and species composition. The two warming plots are warmed continuously from 1st July 2010 using infrared heaters (165×15 cm, MR-2420, Kalglo Electronics Inc., USA) suspended 1.5 m above the ground. The low-level (W1) and high-level (W2) warming plots receive 130 and 150 watts m^{-2} radiation, respectively, and in the control plot a steel frame with the same size as the infrared heater is also suspended 1.5 m above the ground to rule out shading effect of the heater. Distance among blocks is approximately 3 m. One micro-meteorological station was also set up 30-40 m away from the blocks.

2.3 Temperature and soil moisture monitoring

At the center of each plot, a Model HMP45C probe (Campbell Scientific, Inc, USA) was used to automatically monitor air temperature, water vapor pressure and relative humidity at the height of 20 cm aboveground. The temperature and relative humidity probe was put in a shield to avoid direct upward or downward radiation on the sensor; A SI-111 Precision Infrared Radiometer (Campbell Scientific, Inc, USA) was hung 120 cm high aboveground to monitor the surface temperature; four Model 109 Temperature Probes (Campbell Scientific, Inc, USA) were placed to monitor soil temperatures at the depth of 20, 40, 60 and 100 cm underground. All the probes were connected to a CR1000 data-logger (Campbell Scientific, Inc, USA). Air, surface and soil temperatures were recorded every 10 minutes and then averaged on daily basis. Soil moisture measurements were carried out at the depth of 10, 20, 40, 60 and 100 cm under-ground, achieved by using Enviorsmart (Austrilian Sentek) based or frequency domain reflection (FDR). The 10 minutes and averaged daily data were also recorded by CR1000 data-logger.

2.4 Modeling evapotranspiration

A residual energy balance method was selected to determine *ET* for each plot on a daily scale (Kimball *et al.* 1994):

$$\lambda ET = R_n - G_0 - H$$

where λ is latent heat of vaporization (J kg^{-1}), *ET* is evapotranspiration (kg m^{-2} s^{-1}), R_n is the net radiation (W m^{-2}, positive downward), and *H* is the sensible heat flux (W m^{-2}, positive downward).

Net radiation of the micro-meteorological mast was measured using the CNR2 net radiometer (Campbell Scientific, Inc., USA, Utah) 1m over the alpine meadow canopy. The data were recorded at 10 minutes interval and averaged daily. Besides recording R_n, the radiometer also measure upward and downward radiation which could be used to determine the albedo. W1 and

W2 warming manipulation forced 130 and 150 W m^{-2} energy from the infrared heaters. R_n for the control group is derived from the nearby micro-meteorological station and R_n for W1 and W2 treatments are the sum of R_n for control and additional net heat flux, which are the difference between radiation power of infrared heaters and reflected energy.

Soil heat flux of the micrometeorological station was determined from measurements of soil heat flux using soil heat flux plates (Model HFP01, Campbell Scientific, Inc., USA, Utah) at 5 cm. Soil heat flux for W1 and W2 treatments are the sum of soil heat flux of control group and estimate of changes in heat storage resulted from warming.

$$G = G_0 + C\Delta z(\Delta T / \Delta t)$$

where G is the soil heat flux of W1 and W2 treatments, G_0 is the control group soil heat flux, C is the volumetric heat capacity (MJ m^{-3} ^{0}C^{-1}), Δz is the soil depth where soil temperature was measured, ΔT is the change in temperature induced from warming, Δt is the time interval which is one day in this study.

Following Kimball (1994), the volumetric soil heat capacity was calculated using 1.9 MJ m^{-3} ^{0}C^{-1}, 2.5 MJ m^{-3} ^{0}C^{-1} and 4.2 MJ m^{-3} ^{0}C^{-1} for the individual volumetric heat capacities of soil minerals, organic matter and water respectively. Sand fraction in our study site was about 0.95 and studies indicated errors in G should be no more than 2 W m^{-2} if a constant average water volume fraction 0.20 was assumed, therefore C in this study was calculated to be 1.9 MJ m^{-3} ^{0}C^{-1}.

Sensible heat flux was calculated from

$$H = \rho_a C_p (T_s - T_a) / r_a$$

where ρ_a is the air density (kg m^{-3}), C_p is the air heat capacity (J kg^{-1} °C^{-1}), T_s is the surface temperature (°C), T_a is the air temperature at 20 cm height, and r_a is the aerodynamic resistance (s m^{-1}).

Air density was calculated from average station barometric pressure (56.0 kPa). A constant 1020 J kg^{-1} °C^{-1} was used for C_p. T_s of each plot was measure using SI-111 infrared radiometer (Campbell Scientific, Inc., USA, Utah) 80 cm above land surface. T_a was measured in each plot using Model HMP45C temperature probe (Campbell Scientific, Inc., USA, Utah) at 20 cm height.

Following Kimball (1994), the aerodynamic resistance was computed from the 0.5 m wind speed using Met-One sensor (Model 014A, Campbell Scientific, Inc., USA, Utah).

$$r_a = \frac{1}{u}\left\{\frac{1}{k}\ln\left[\frac{z - d + z_0}{z_0}\right]\right\}^2 \Phi$$

where u is the wind velocity (m s^{-1}) at the measuring height z (m), z_0 is the roughness length (m), k is the von Karman's constant (0.40), d is the zero-plane displacement (m), and Φ is the stability correction.

The zero displacement and the roughness length were calculated from measured canopy height, h (m) using equations from Monteith (1973)

$$d = 0.63h, z_0 = 0.13h$$

In our study, T_s is always greater than T_a which suggests unstable conditions and Φ was calculated from Mahrt and Ek (1984) with minor modification:

$$\Phi = \{1 - 15Ri / [1 + K[|Ri|^{1/2}]\}^{-1}$$

where Ri is Richardson number $Ri = g(Ta - Ts)(z - d) / [(Ta + 273.16)u^2]$,where g is the acceleration of gravity (9.81 m s^{-1}) and $K = 75k^2[(z - d + z_0) / z_0]^{1/2} / \{\ln[(z - d + z_0) / z_0]\}^2$.

ET is commonly estimated as a soil moisture-limited fraction of a potential rate (Albertson and Kiely 2001). A linear limitation function on *ET* was adopted to estimate daily *ET* of savanna landscapes and estimated results showed good agreement with the tower-based measurements (Williams and Albertson 2004). Therefore, ratio between soil water content in 0-10 cm and field capacity of 0-10 cm was used to linearly correct the *ET* derived from the residue energy balance method.

2.5 Verification of evapotranspiration

To verify the modeled *ET*, micro-lysimeter were installed in each plot in 2011. The lysimeter consists of a balance and a cylinder 0.19m in diameter and 0.5 m in height, made of PolyVinyl Chloride (PVC) . The cylinder was filled with soil column excavated nearby the plots by using a tailor-made cutting ring. A hole with the same size as the cylinder was dug in center of each plot to hold the soil column. Coverage and species composition of the soil column was similar as experimental plots as much as possible. The weight of each lysimeter was measured every day at 8:00 am in August, 2011. If there were a rainfall event, measurements would be delayed to 20:00. *ET* was the balance between soil column change and rainfall amount.

2.6 Partitioning of soil evaporation (E_a) and plant transpiration (T_r)

Alpine grass was dormant from November to next May in the study site, therefore estimated *ET* in this time period was treated as E_a. Correlation analysis was conducted between E_a and latent heat, wind speed at 50 cm, water vapor deficit at 20 cm, soil moisture at 10 cm, air temperature at 20 cm and soil temperature at 20 cm. Results showed that latent heat, soil moisture at 10 cm and soil temperature at 20 were the three factors that affect evaporation at winter time. Linear regression was conducted between E_a and latent, soil moisture and soil temperature. The equation was $Ea = -0.139 + 0.004 \times LH + 0.047 \times \theta + 0.005 \times T$,R^2=0.89, where LH was soil latent heat, θ was the soil water content of 0-10 cm (%), T was the soil temperature at 20cm. E_a of alpine meadow in the growing period was estimated using the same linear regression relationship as in winter time. Differences between *ET* and E_a were the T_r. *ET*, E_a and T_r were calculated on a daily base and then were averaged monthly.

2.7 Data analysis

All the data analyzed in this study were collected from the experiment plots within the first year (July 1st 2010 to 2nd July 2011). Statistical significance of warming on energy components, soil moisture and evapotranspiration were evaluated by the ANOVA.

3. Results

3.1 Soil moisture

The total precipitation from 1st July 2010 to 2nd July 2011 was 318.3 mm with most occurring from May to October (Fig.1). Annual mean surface and soil temperatures were significantly increased by warming and warming effects in W2 was greater than in W1 (Fig.1). Soil moisture at the soil layer of 0-10 cm was closely associated with precipitation variation. We therefore defined two seasons, cold-dry season (November to next April, alpine meadow grass is dormant in this period) and warm-rainy season (May to October) for the study site. Experimental warming significantly reduced annual mean soil moisture at shallow layers (0-10 and 10-20 cm, Fig.1). Warming effects on annual mean soil moisture had no significance in W1 and W2 treatments.

3.2 Energy balance

The three energy dissipation ways decreased in order: latent heat, sensible heat and soil heat flux in all treatments (Fig.2). Latent and sensible heat flux accounted for more than 90% of the net radiation. Annual mean net radiation, latent, sensible, and soil heat flux in control were respectively 83.21, 55.81, 31.31, and -3.91 W m^{-2}. W1 and W2 treatments respectively increased net radiation by 94.38 and 108.9 W m^{-2} (P<0.001); sensible heat flux by 46.71 and 57.68 W m^{-2} (P<0.001); latent heat flux by 42.71 and 40.62 W m^{-2} (P<0.001), soil heat flux by 4.95 and 10.58 W m^{-2} (P<0.001).

3.3 Evapotranspiration

The energy balance model and soil moisture correction function well predicted *ET*. Warming treatments improved the fitness of observed and measured *ET* (Fig.3).

The temporal variation of *ET* followed the seasonal patterns of precipitation, soil moisture, net radiation and latent heat, which was higher in warm-rainy season and lower in cold-dry season (Fig.4). Annual accumulative *ET* was 311, 403.65, and 400.18 mm in C, W1 and W2 treatments, respectively. Daily mean *ET* was 0.85 mm day^{-1} in control plots and increased by 0.253 (P=0.0009) and 0.243 mm (P=0.0004) in W1 and W2 treatments, which corresponds to an

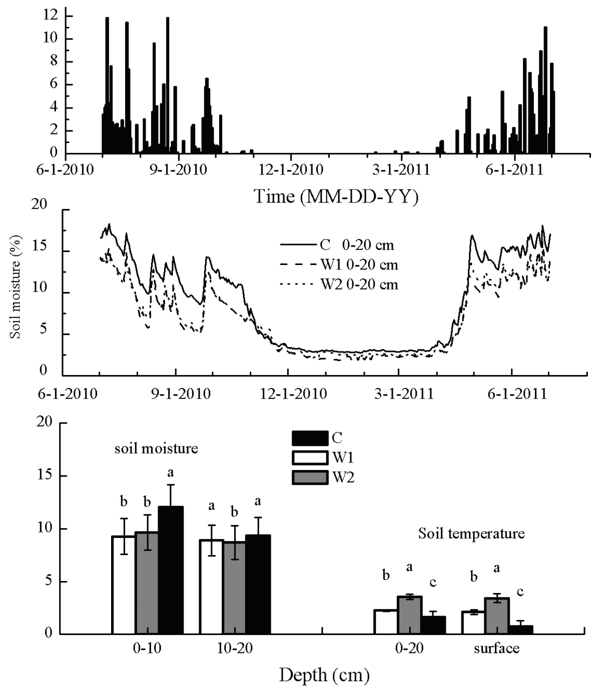

Figure 1: Annual variation of precipitation (A) and soil moisture at the layers of 0-20 under the control (C), low-level (W1) and high-level (W2) warmed treatments (B). Panel C showed annual mean soil moisture at the layers of 0-10, 10-20, and surface temperature and 0-20 cm soil temperature. Precipitation data were derived from the meteorological mast near the experimental plots. Soil moisture and temperature data were averaged from five replicates. Different symbols above the column denote the significant difference (p = 0.05, n=5).

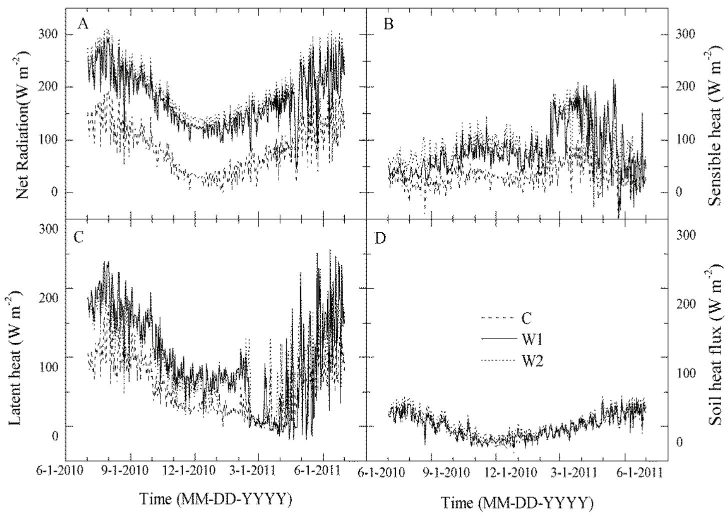

Figure 2: Annual dynamics of net radiation, sensible, latent and soil heat flux under control (C), low level (W1) and high level (W2) warming. Values are the average of five replicates.

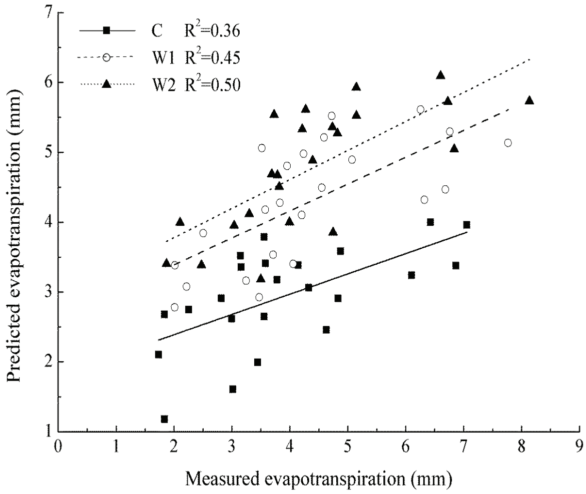

Figure 3: Measured vs. modeled evapotranspiration of the control (C), low level (W1) and high level (W2) warming treatments. Evapotranspiration measurements were conducted in August, 2011. Measured and modeled values are the average of five replicates.

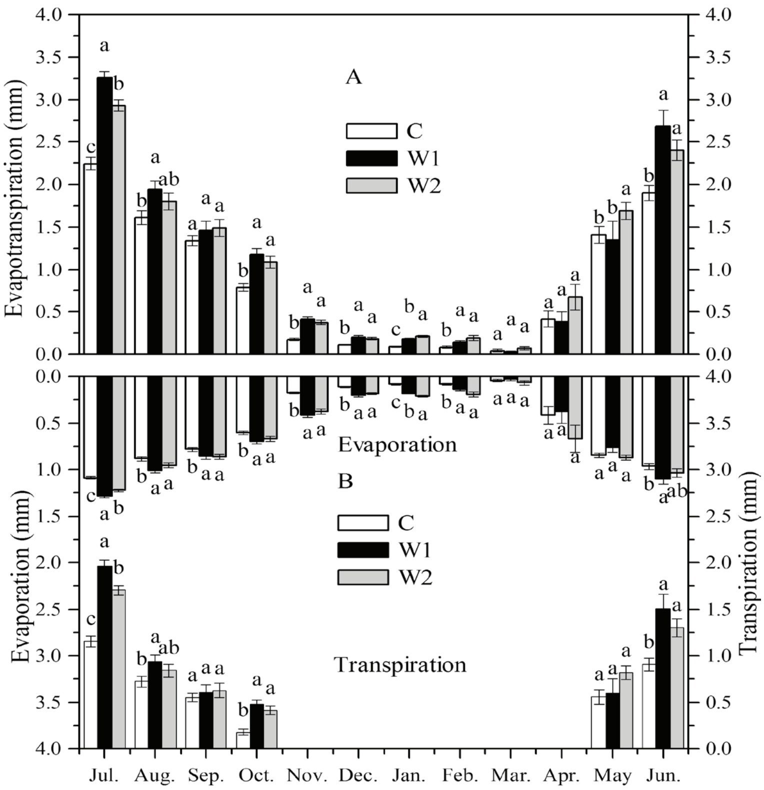

Figure 4: Monthly average evapotranspiration (A), soil evaporation and plant transpiration (B) under control (C), low level (W1) and high level (W2) warming treatments. Bars labelled with different letters indicate the significance at p≤0.05.

increase of 29.76% and 28.58%, respectively. *ET* varied between warm-rainy season and cold-dry season (Fig.5). W1 and W2 treatments increased daily mean *ET* 0.37 and 0.34 mm in warm-rainy season, and 0.10 and 0.11 mm in cold-dry season.

3.4 Soil evaporation and plant transpiration

Annual E_a was 179.81, 208.93 and 213.18 mm, which was 57.76%, 51.76% and 53.28% of annual *ET* in C, W1 and W2 treatments, respectively. W1 and W2 treatments increased annual E_a by 16.19% and 18.55% (P<0.001), respectively. Annual dynamics of E_a was the same as that of *ET* (Fig. 4). Cold-dry season E_a was 20.46, 33.11 and 39.93 mm in C, W1 and W2 treatments, which was 11.35%, 15.85% and 18.73% of total annual E_a. E_a increased 12.65 and 19.47mm in cold-dry season and 16.47 and 13.9 mm in warm-rainy season in W1 and W2 treatments, resp T_r made up 43.82, 51.57 and 50.34% of *ET* in the warm-rainy season in C, W1 and W2 treatment plots. T_r was marginally smaller than E_a in control plots (P<0.001) , while T_r was higher but non-significant than E_a in W1 (P=0.32) and W2 (P=0.78) treatments in the warm-rainy season (Fig.5). T_r increased by 63.53 (P<0.001) and 55.81 mm (P<0.001) in W1 and W2 treatments, respectively.

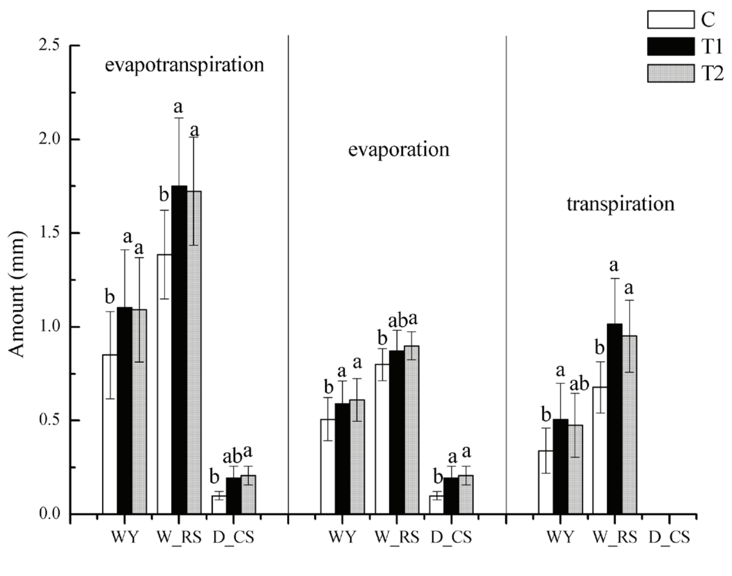

Figure 5: Daily average evapotranspiration, soil evaporation and plant transpiration of the whole year (WY), warm-rainy season (W_RS) and dry cold season (D_CS) in control (C), low level (W1) and high level (W2) warming treatments. Bars labelled with different letters indicate the significance at p≤0.05.

3.5 Relationship between water content and evaporation and transpiration

Evaporation and transpiration were both positively related to soil water content of the 0-10 layer in all three treatments. Effect of soil water content on evaporation decreased while it increased on transpiration with warming (Fig.6).

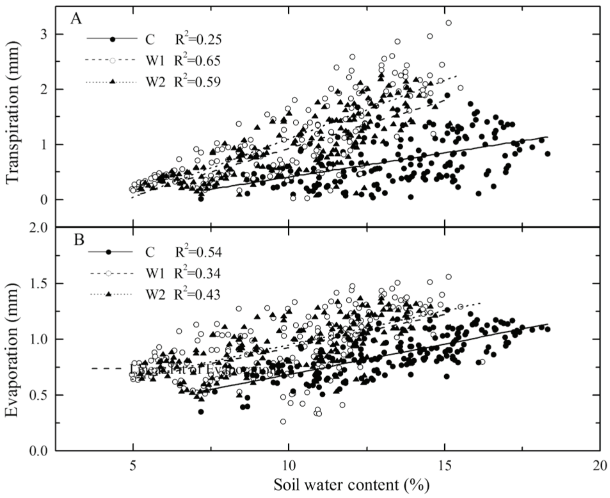

Figure 6: Relationship between soil water content (0-10 cm) and transpiration and evaporation in warm-rainy season under control (C), low level (W1) and high level (W2) warming (n=183, $p<0.05$).

4. Discussion

4.1 Energy balance response to warming

Net radiation, sensible, latent and soil heat flux of the alpine ecosystem near our study site was averaged to be 137.7, 37.9, 51.7 and 8.4 W m^{-2} from May to June (Qian *et al.* 2005). In our study, net radiation, sensible, latent and soil heat flux from May to June in control group were 123.53, 26.87, 82.47 and 14.19 W m^{-2} respectively, which support the correctness to apply the energy approach in calculating different energy components. Infrared heaters as the warming installation are most true to simulate natural increase in downward radiation, and to the climate change predictions (Aronson and McNulty 2009). R_n dissipated in the form of latent, sensible and soil heat flux, which are responsible for variation in *ET*, air temperature and soil temperature. Though sensible heat flux increased in our study, air temperature was found to have no significant change because of the strong wind in the study area (Xue *et al.* submitted).

4.2 Evapotranspiration response to warming

ET was estimated to be 311 mm in control treatment, which is smaller than 425.5 mm in alpine meadow that receives more precipitation (Liu *et al.* 2010). *ET* is the largest component of water loss from ecosystems in terms of terrestrial water cycle (Gu *et al.* 2008). In this study, 95% precipitation returned to atmosphere through *ET* in control treatment, which is in agreement with the conclusion that most of the precipitation loss is in the form of *ET* near our study site (Lu *et al.* 2006) and in tussock grassland (93%) (Hunt *et al.* 2002). It is often assumed that in mountain areas *ET* will increase in a warmer global climate (Beniston 2003). *ET* estimation from precipitation and runoff showed *ET* increase in 16 catchments in Tibet Plateau from 1966 to 2001 under climatic warming (Zhang *et al.* 2007). W1 (1.88^{o}) and W2 (3.19^{o}) treatments increased *ET* by 29.76% and 28.58%, respectively, which was greater than the *ET* increase (14.8%) with 4-8^{o}C temperature increase in arid zone of India (Goyal 2004). Plant canopy phenological changes as a result of earlier onset of the non-frozen season generally promote annual *ET* in colder areas (Zhang *et al.* 2011) besides the direct effects of environmental parameters (Obrist *et al.* 2003). Advancement in thawing of permafrost active layer (Xue *et al.* submitted) probably contributed the large increasing amount of *ET*.

4.3 Evaporation and transpiration responses to warming

Plant transpiration (T_r) accounts for about 52% of total *ET* globally (Lawrence *et al.* 2007a) with variation in different ecosystems. T_r accounted for about 50% to annual *ET* in a temperate semi-arid grassland ecosystem (Niu *et al.* 2008), while it was only 22% in a sparse grassland at the edge of the Eurasian cryosphere in Mongolia (Zhang *et al.* 2005). Estimated T_r was 43.82, 51.57 and 50.34% of *ET* in growing season in C, W1 and W2 treatments. The proportion of water loss by soil evaporation (E_a) during the growing season ranged from nil to about 40% and to >90% in the dormant season (Ferretti *et al.* 2003). E_a in growing season accounted 43% for *ET* in warming treatments, and 51% in control treatments.

As global mean surface temperature increases, the saturation vapor pressure increases, thereby enhancing evaporation. By the year 2050, global mean evaporation would increase by 5.2% with a 2.3°C increase in surface air temperature (Wetherald and Manabe 2002). W1 and W2 treatments increased annual E_a by 16.19% and 18.55% (P<0.001), respectively. Larger E_a increase in W2 than in W1 suggests no water limitation on E_a since water decrease in W1 and W2 had no difference (Fig.1). E_a will greatly decrease when leaf area index (LAI) is greater than three in a growing season (Obrist *et al.* 2003). In our study, LAI was smaller than 2.0, therefore, E_a still increased even in the warm-rainy season.

T_r increase could be either the result of absorbing more biologically available water and decreasing amount of soil evaporation (Bell *et al.* 2010), an increase in total biomass (Ferretti *et al.* 2003), or changing in phenology (Obrist *et al.* 2003). T_r increased by 57% with a 10°C rise in a tallgrass prairie (Bell *et al.*, 2010). In this study, W1 and W2 increased T_r by 48.4% and 55.81%. The greater T_r relative increase per degree in our study were probably the results of extended growing season as warming advanced active layer thawing and delayed freezing (Xue *et al.* submitted) and projected aboveground biomass promotion evidenced in a remote sensing study (Yang and Piao 2006). *Tr* has no significant difference in May and September (Fig. 4) between warming and control treatments as alpine meadow growth was only promoted in summer season (Yang and Piao, 2006). Rare rainfall (Fig.1) and consequent lower soil water content in those two months limit the warming effects on T_r.

5. Conclusion

Water balance regulates the alpine meadow ecosystem development. Soil water in the surface layer of the alpine meadow ecosystem decreased due to warming. Significant increase in evapotranspiration led to the water loss in surface layer. T_r proportion to *ET* was about 50%, similar as in the temperate grassland in semi-arid areas. Annual E_a increased 29.12 and 33.37 mm, and T_r increased 63.53 and 55.81 mm with W1 and W2 treatments, respectively. The results suggest that water loss is mainly in the way of plant transpiration under climatic warming. No significant difference in evapotranspiration, evaporation and transpiration were observed with warming levels as soil water content decline offset direct effects of warming on *ET*. The results indicate indirect role of soil water content on *ET* change under climatic warming in the Qinghai-Tibet Plateau.

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Management and utilization of saline water and salt-affected arid land resources by raising salt tolerant grasses and trees

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Abstract

Salinity is a major cause of water and soil pollution in the arid and semiarid regions of the world, particularly in the Middle East and South Asia. Low quality irrigation water is a major contributing factor in converting arable lands to saline lands. Due to soil and water salinity, the sustainability of agriculture in Pakistan and in the other parts of the world is threatened. In order to achieve the agriculture and environmental sustainability there it is necessary that the salt-affected waters and soils are properly managed. The introduction of highly salt tolerant plant species along with appropriate agronomic practices and alterations in their utilization patterns offers a viable option for the management and utilization of these resources in the arid environments. Raising salt tolerant woody plants along with shrubs and grasses is not only cheap but also a profitable practice and can make salt-affected soils a healthy component of the overall environment. This paper describes the successful raising of salt tolerant tree and forage species on a salt-affected land using saline water and thus demonstrates the management and utilization of the saline soil and water resources in the arid environments.

Introduction

Soil salinity is a major agricultural and environmental problem in the arid and semiarid regions of the world, particularly in the Middle East and South Asia. Low quality irrigation water is a major contributing factor in converting arable lands to saline lands (Qadir and Schubert 2002). The estimated total salt-affected area of the world is over 800 mha (Munns 2005) and of Pakistan is about 6.67 mha (Khan1998).

The use of saline-sodic soil and water in agriculture seems inevitable (Qadir and Oster 2004; Bouwer 2002; Beltran and Manzur 2005) to feed and improve the livilihood of the people of the affected areas in particular and of the other areas in general. This is also important to decrease the disposal problem of the poor quality drainage water and for the rehabilitation of the degraded barren lands as the good quality water availability for these lands does not seem possible in future. The cultivation of the barren lands also contributes to the environmental conservation through carbon sequestration (Lal 2001), ecological rehabilitation and reduced erosion.

The reclamation of the salt-affected soils through engineering or chemical approach is very expensive. Many salt affected soils are not even treatable and this approach is also not sustainable over long time (Qureshi and Barret-Lennard 1998).The biological approach of growing salt-tolerant plant species provides another option. Plant species and their varieties differ in their ability to grow on salt-affected soils (Maas and Hoffman 1977) however, the crop species are usually the glycophytes and are able to grow upto a low to medium level of salinity (Lauchli and Epstein 1990). Halophytes are the salt-tolerant plant species which may be grown on salt-affected lands using saline waters.

Adopting a halophytic plant based strategy will help the rural economies directly by supplying fodder and fuel wood and indirectly by advancing the ecological rehabilitation and sustainable agro-ecosystem development. In India, it has been reported that using trees in agriculture contributes to biodiversity conservation, yields goods and services to the society, augments the carbon storage in agro-ecosystem, enhances the fertility of the soils, and results in the social and economic well-being of the people (Pandey 2007). The salt-tolerant halophytic plants have shown potential under saline environment in India (Tomar *et al.* 2002), Pakistan (Qureshi *et al.* 1993) and Australia (Barrett-Lennard 2002). A study in Pakistan revealed that the contribution of annual crops and the tree component into agroforestry income was 63 and 37% respectively, and tree component increased the overall household farm income and minimized the dependency on natural forest for fuel wood and timber with a positive impact on natural forest conservation (Essa 2004). Keeping the above observations in view the present study was conducted to demonstrate the possibility of management and utilization of saline waters on salt-affected arid land by raising salt tolerant tree and forage species.

Materials and methods

Experimental site and plant species

This study was conducted at the research farm of the University of Agriculture, Faisalabad, Pakistan. Faisalabad is situated at 73.4° longitude and 31.5° latitudes. The average meteorological data during the study period are given in Table 1. The data of six tree and three grass species are detailed in Table 2.

Table 1: Meteorological data during the study period (July 2010-June 2011)

Month	Temperature			R.H.	Rain fall	PAN evaporation	Net sun shine	Wind speed
	MAX	MIN.	Avg.					
	ºC	ºC	ºC	%	TOTAL (mm)	mm	hours	Km/h
July '10	36.0	27.9	31.9	63.6	277.8	06.8	09.0	08.1
August	34.9	26.1	30.5	74.6	226.6	04.9	06.0	06.5
September	33.9	23.3	28.6	66.77	86.5	04.8	07.88	05.7
October	32.9	19.7	26.3	59.58	00.0	03.5	07.57	03.3
November	27.1	10.5	18.8	62.27	00.0	02.5	08.53	02.6
December	21.0	05.8	12.9	70.36	00.0	01.3	07.29	03.1
January '11	15.9	04.3	10.1	73.4	00.0	01.3	05.40	04.3
February	20.2	08.7	14.4	73	26.0	01.7	05.50	06.2
March	26.4	13.1	19.8	59.8	06.8	03.5	08.40	05.8
April	32.0	17.2	24.8	47	20.9	05.9	09.30	07.2
May	40.6	24.9	32.8	43	14.6	08.8	10.40	08.0
June	38.6	26.0	32.3	55	78.3	07.9	09.38	05.6

Nursery raising

The seeds of the selected tree species were soaked in warm water for about 2 hours before sowing in small plates containing nutrient solution (Hoagland and Arnon 1950) solidified by the addition of agar. The plates were placed in an incubator until the seeds germinated and seedlings emerged. The seedlings were transplanted to the polythene bags (0.10 wide, 0.22 m long) having about 12-16 small holes of about 0.01 m diameter and containing silt-compost mixture (2:1 ratio) placed in excavated soil beds in a non-saline field. The cuttings of the *Leptochloa fusca* and *Panicum antidotale* were prepared and planted in the similar polythene bags. Irrigation was applied to the bags through seepage by applying water to the excavated beds. The bags were covered with polythene sheet to avoid cold stress in the winter months.

Table 2: The plant species used in this study

S. No.	Plant species	Potential use	Salt tolerance	Country of study	Reference*
1	*Acacia ampliceps* (local name: Australian kikar)	• As fuel and fodder • As a windbreak and soil conservation agent	ECe: 15-20 dS m-1	Australia	Marcar *et al.* (1995)
2	*Acacia nilotica* (local name: kikar)	• As fuel, fodder, timber, gum and lac.	ECe: 15-21dS m-1	Pakistan	Qureshi *et al.* (1993)
3	*Albizzia lebbeck* (local name: shirin)	• As fuel, fodder and ornamental plant • As a windbreak and soil conservation agent	ECe: 15-21dS m-1 SAR: 38	Pakistan	Qureshi *et al.* (1993)
4	*Leucaena leucocephala* (local name: iple iple)	• As fuel and fodder • As a nitrogen fixing agent	ECe: 14 dS m-1 SAR: 30	Pakistan	Qureshi *et al.* (1993)
5	*Zizyphus mauritiana* (local name: beri)	• As a fruit • As fuel, fodder and lac.	High salinity and sodicity tolerant	Pakistan	Qureshi *et al.* (1993)
6	*Azadirachta inidca* (local name: Neem)	• As a medicinal plant • As a shade plant	Salt tolerant	India	Ahmad and Chang (2002)
7	*Sorghum sudanese* (local name: sudan grass)	• As fodder • For revegetation of saltlands	ECe: 14 dS m-1	Pakistan	Malik *et al.* (1986)
8	*Leptochloa fusca* (local name: Kallar grass)	• As fodder and for production of mushrooms and biogas • As a soil cover and biological reclamation agent	ECe: 22.3 dS m-1 SAR: 150	Pakistan India	Malik *et al.* (1986); Gupta and Abrol (1990)
9	*Panicum antidotale*	• As fodder • As a soil cover	15.0 dS m-1	Pakistan	Akhtar and Hussain (2008)

Soil and water sample collection and analysis

Soil samples were collected from 0-30 cm soil depths from the experimental site at the start and at the end of the experiment and at the time of data collection. The water samples from the available tube well were taken after 30 minutes of the start of the tubewell and were stored in the clean plastic bottles. These soil and water samples were analyzed for electrical conductivity

(EC), pH, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC; for water only) following the methods given by Richards (1954).

Field preparation and nursery transplantation

The field was precisely leveled by laser leveling and prepared by plowing and planking. The field was divided into small plots for each individual plant species. In each plot 0.3 m deep furrows were made and on the one side of these furrows small pits of 0.60 x 0.15 x 0.15 m (depth x width x length) dimensions were excavated. The plant to plant and row to row distance was maintained at 2 m and 3 m, respectively. The healthy and uniform seedlings from the nursery were selected and transplanted in the excavated pits after cutting the bags from the bottom. Small amount (about 0.5 kg) of silt-compost mixture (2 x 1) was placed in each pit before the transplantation of the seedlings. Afterwards the plants were irrigated with the available saline water and the cultural practices like hoeing and weeding were carried out as and when needed.

Plant data collection

After eight months of transplantation, data on plant height, stem circumference (for trees only) and weight (for grasses only) were collected. Plant leaf samples were also collected and analysed for Na^+, K^+ and Cl^- following Saqib *et al.* (2005).

Results

The plant growth parameters were recorded and averaged on six selected plants. Among the different tree species *Albizzia lebbeck* produced the maximum and significantly higher plant height than the other trees whereas *Acacia ampliceps* produced the minimum plant height followed by *Acacia nilotica* and *Zizyphus mauritiana* in an ascending order (Fig. 1). *Albizzia lebbeck* also produced the maximum stem circumference where as the other tree species produced a statistically similar stem circumference (Fig. 2). The grass species differed significantly for plant height as well as for the fresh weight production. *Sorghum sudanese* produced the maximum plant height as well as fresh weight followed by *Panicum antidotale* and *Leptochloa fusca* in a descending order (Fig. 1, 3).

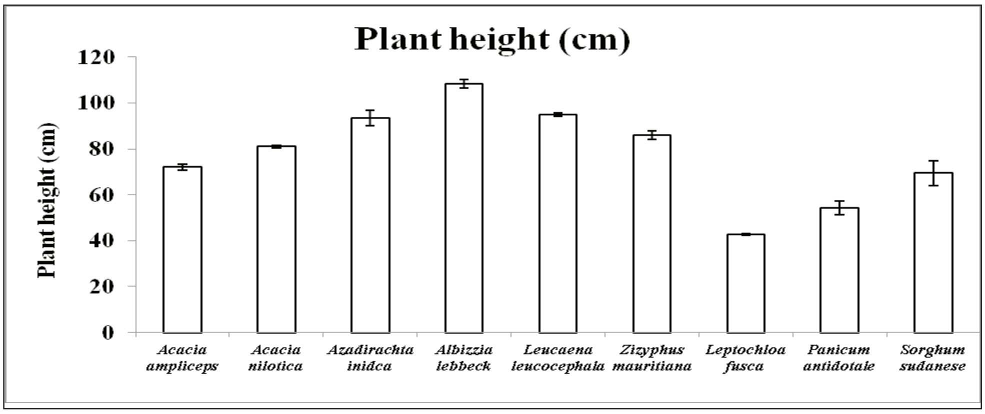

Figure 1: Performance of different tree and grass species in terms of plant height (cm) in a salt-affected field.

There were plant to plant differences in the individual tree species and a comparison of good and poor plants showed significant differences among them for plant height as well as stem circumference (Fig. 4 and 5, data shown for *Acacia nilotica* and *Leucaena leucocephala* only).

A comparison of the leaf ionic composition showed a significantly higher Cl^- concentration and lower K^+ concentration in the poor plants of *Acacia nilotica* than in its good plants (Fig. 6). However, in the case of *Leucaena leucocephala*, the poor plants showed a significantly higher Na^+ and Cl^- concentration than the good plants. The ionic composition of the grass species showed that *Sorghum sudanese* accumulated less Na^+ and Cl^- in its leaves than *Leptochloa fusca* and *Panicum antidotale* (Fig. 7). However the K^+ concentration was almost same in the three grasses.

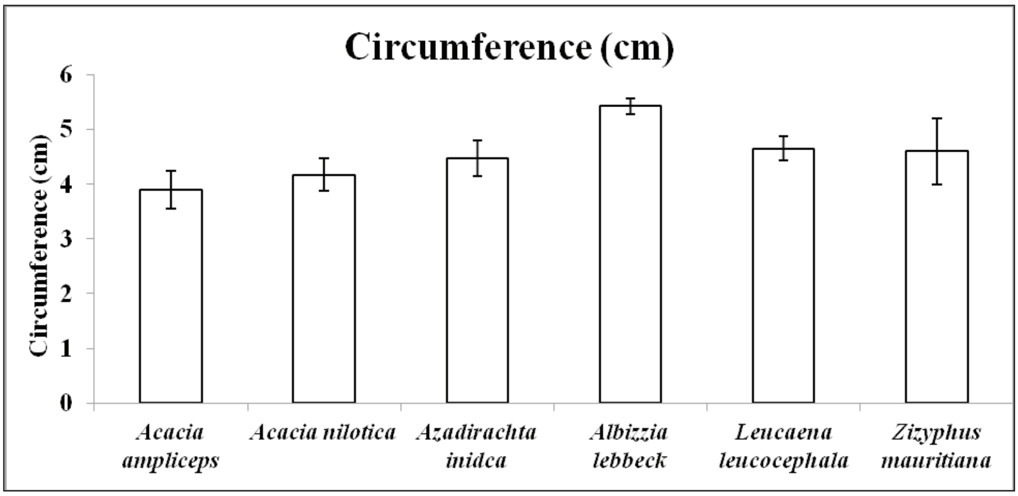

Figure 2: Performance of different tree species in terms of stem circumference (cm) in a salt-affected field.

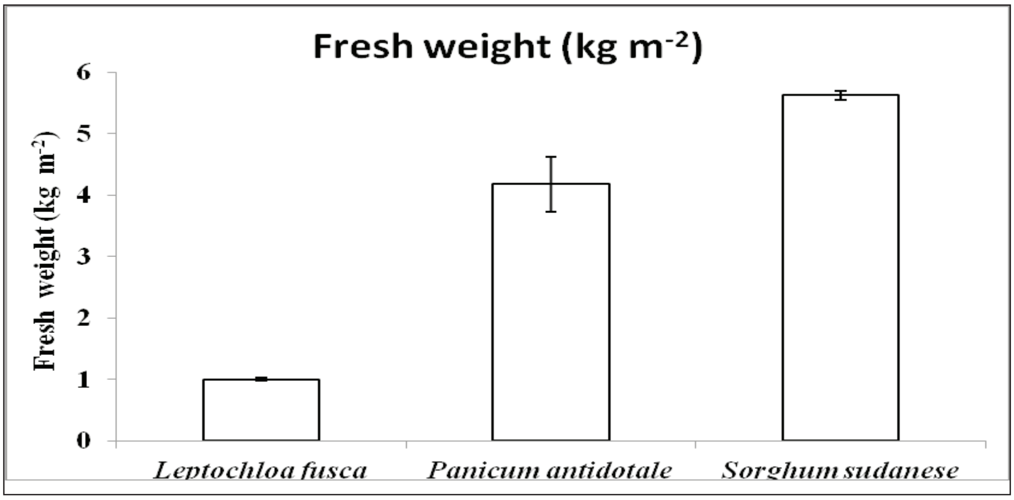

Figure 3: Performance of different grass species in terms of fresh weight (kg m^{-2}) in a salt-affected field.

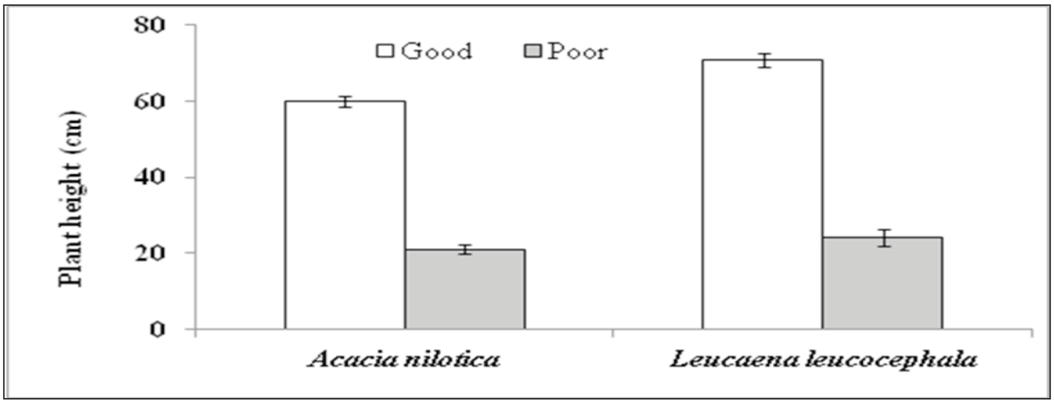

Figure 4: Performance of different tree species in terms of plant height (cm) in a salt-affected field.

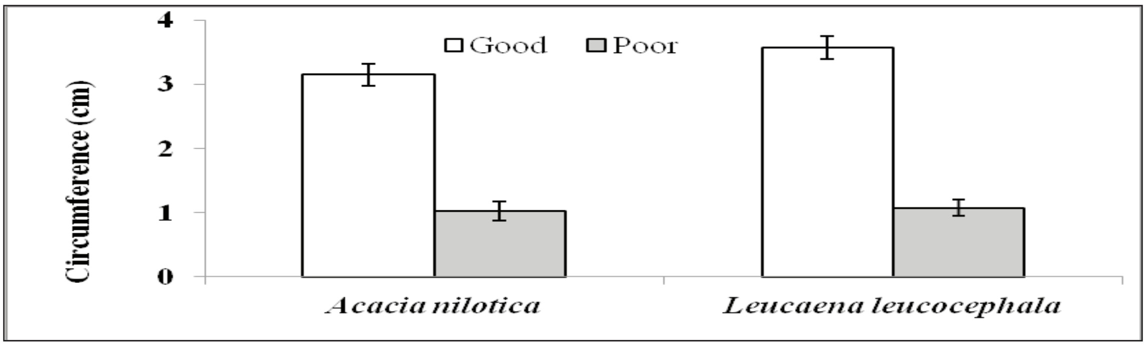

Figure 5: Performance of different tree and grass species in terms of stem circumference (cm) in a salt-affected field.

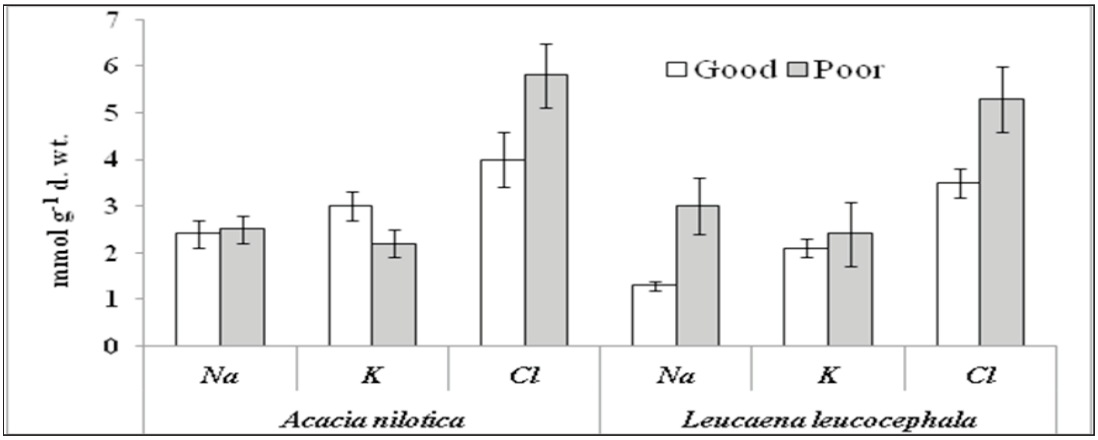

Figure 6: Leaf ionic composition of two tree species in a salt-affected field.

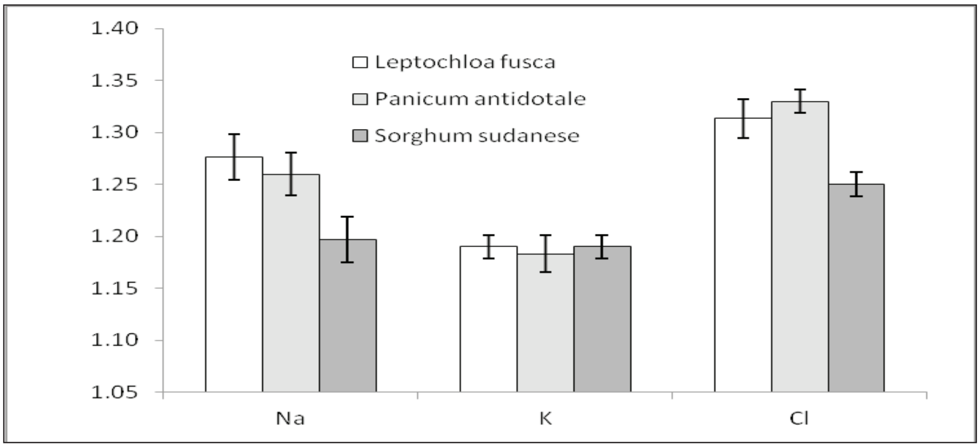

Figure 7: Leaf ionic composition (mmol g^{-1} d. wt.) of different grass species grown under salt-affected filed conditons.

Soil analysis data of the field showed that it was a saline-sodic field owing to high values of pH, ECe and SAR. Within each plot there were differences regarding these parameters which are indicated by the differences in the growth of the plants (Fig. 8). The soil analysis for pH, ECe and SAR for grasses is shown in Fig. 9. SAR value of soil was higher under *Sorghum sudanese*. The available water used for raising the plant species at the experimental site was tube well water. The analysis shows that it is saline-sodic water (Table 3) as it has higher values of EC and SAR than the permissible limits.

Table 3: Analysis of the available water at the experimental site

Characteristics	Unit	Tube well water
EC	dS m^{-1}	3.84
TSS	($mmol_c$ L^{-1}	38.4
SAR	(mmol $L^{-1}$$)^{1/2}$	17.92
RSC	($mmol_c$ L^{-1}	Nil

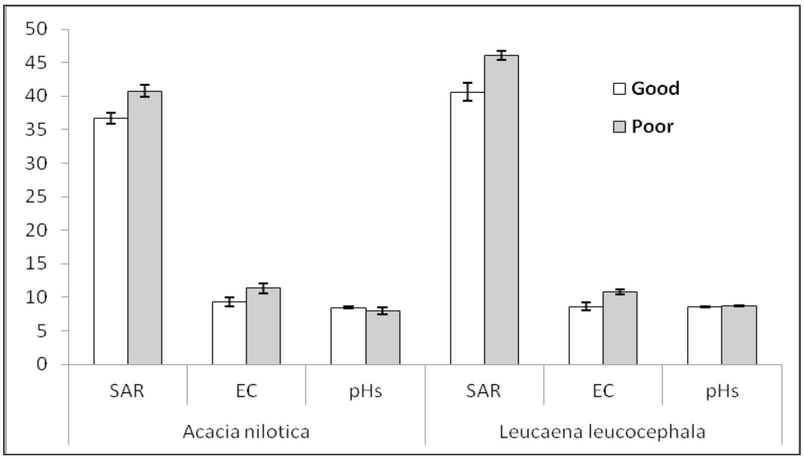

Figure 8: Soil analysis data of the salt-affected field used to raise *Acacia nilotica* and *Leucaena leucocephala* (SAR: (mmol $L^{-1}$$)^{1/2}$, EC: dS m^{-1}).

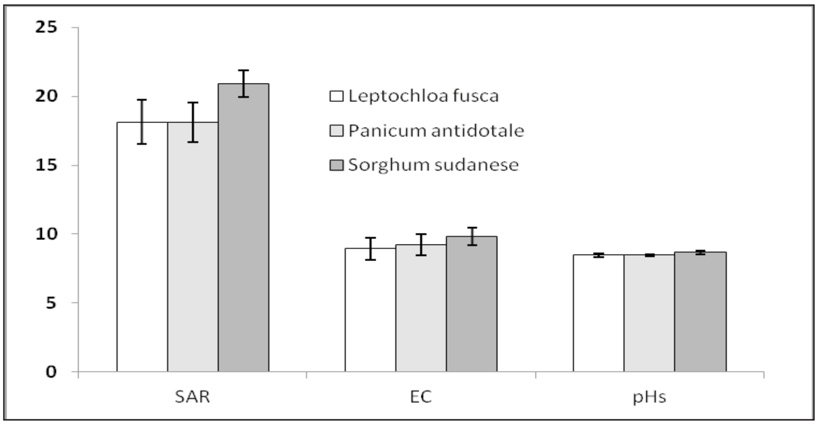

Figure 9: Soil analysis data of the salt-affected field used to raise different grass (SAR: (mmol $L^{-1})^{1/2}$, EC: dS m^{-1}).

Discussion

Salinity creates many problems for plant growth. These include high concentrations of soluble salts, nutrient deficiency/imbalance and effects on water uptake. High salt stress causes problems at both the cellular and the whole plant levels and also results in oxidative damage to the plants. The disturbed ion and water homeostasis may cause molecular damage, stunted growth and even death of the plants (Zhu 2001). The sodicity causes surface crusting due to slaking, swelling and dispersion of clay (Shainberg and Letey 1984; Quirk 2001) and thus disturbs the water permeability, aeration, water holding capacity and root penetration. In addition, imbalanced plant nutrient availability in both saline and sodic soils affects plant growth (Naidu and Rengasamy 1993). The use of saline-sodic water also adversely affects the soil quality and plant growth (Qadir and Schubert 2002).

In this study all the plant species got established in the hard saline-sodic field conditions and performed well which demonstrates their salt tolerance (Fig. 1-3). Among the different tree species *Albizzia lebbeck* produced the maximum and significantly higher plant height than the other trees whereas *Acacia ampliceps* produced the minimum plant height. Likewise stem circumference was more in case of *Albizzia lebbeck* as compared to the other species. Leaf ionic composition showed a significantly higher Cl^- and lower K^+ concentration in the poor plants of *Acacia nilotica* (Fig. 6). On the other hand, the poor plants of *Leucaena leucocephala*, showed a significantly higher Na^+ and Cl^- concentration than the good plants. These data show that in *Acacia nilotica* Cl^- toxicity and K^+ deficiency are more important growth determinants where as in *Leucaena leucocephala* both Na^+ and Cl^- toxicity are the important growth determinants. Maintaining higher K^+ or lower Na^+ in the good plants would have helped them to maintain higher K^+: Na^+ ratio in both the species which shows a common importance of K^+: Na^+ ratio in *Acacia nilotica* as well as *Leucaena leucocephala*. The maintenance of better K^+: Na^+ ratio has also been considered an important determinant of salt resistance in other species (Qureshi and Barret-Lennard 1998; Saqib *et al.* 2005).

This also seems to be true for the grass species *Sorghum sudanese* which produced higher fresh weight, and accumulated less Na^+ and Cl^- in its leaves than *Leptochloa fusca* and *Panicum* *antidotale* (Fig. 7). As discussed earlier salinity and sodicity of soil and water adversely affects plant growth and development. However, the plants differ in their salt tolerance and the survival and growth of the selected plants under these water and soil conditions demonstrate their salinity and sodicity tolerance. The occurrence of poor and good plants and difference in their leaf ionic composition shows inter and intra species difference for salinity and sodicity tolerance in the studies plants (Fig. 4-6). In the past, Malik *et al.* (1986) and Maas and Grattan (1999) also found certain grass species very suitable for growing on salt affected soils. Earlier researchers have also reported differences for salt tolerance among the plant species (Qureshi *et al.* 1993; Akhtar and Hussain 2008).

Conclusions

The utilization of salt-affected soils and water is a necessity because of shrinking normal soil and water resources and increasing population. This study shows that the management and utilization of saline waters on salt-affected arid land can be done successfully by raising salt tolerant tree and forage species. This study further shows that intra specific variation exist for tolerance to salinity and sodicity and it should be further exploited for better utilization of arid land resources.

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Assessment of sexual vs asexual reproduction in *Prosopis cineraria* in the United Arab Emirates using seed pod observations

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Abstract

Distribution of *Prosopis cineraria* in the United Arab Emirates (UAE) varies from open forests in gravelly wadi beds to tight clusters in low sand dunes. Observations of pod production were used to test the hypothesis that clustering was due to asexual reproduction, while open forests were derived sexually. Flowers are self-incompatible and insect pollinated, thus requiring pollination from a genetically different tree to produce fruit. Observations of pod distributions on 591 trees in open, clustered, and mixed forests could all be explained by the hypothesis. Findings indicate that large clusters containing hundreds of genetically identical trees are common, and that asexual reproduction is far more frequent in the region than is sexual. Conservation efforts should facilitate both forms of reproduction within the species' natural range. Food sources for native wildlife, and for livestock, could both be enhanced by increasing the rate of outcrossing during pollination in clonal forests.

Introduction

Ghaf (*Prosopis cineraria*) is the dominant tree species across most of the northern United Arab Emirates (UAE). It has an important place in the cultural heritage and ecology of the region (Lemons *et al.* 2003). Under natural conditions, tree distribution of *P. cineraria* has been observed to occur either as an open forest (Jongbloed *et al.* 2003), typically in gravelly areas such as wadi beds, or in distinct clusters of variable size (Aspinall 2001; Gallacher and Hill 2005), typically on dunes covering a gravel substrate. These two distribution modes often overlap geographically, thus presenting as an open forest that contains, or is dominated by, tighter clusters. Within Oman, *ghaf* forests are associated with underlying aquifers, in which clusters can also be observed (Brown 1988). However, clustering has not been reported elsewhere in the species' natural habitat, suggesting that it may be a feature specific to the Arabian Peninsula population.

P. cineraria has become a preferred species in the extensive afforestation projects within Abu Dhabi emirate, and for shelterbelts and roadside plantations throughout the UAE. As a native species, it is perceived to use water more efficiently than non-natives, and its extensive root system is useful for stabilizing sand dunes. Artificial forests comprised of *P. cineraria* were found to contain enhanced floral diversity and an improved soil fertility, when compared to un-forested rangeland, and artificial forests of *Acacia tortilis* and *Ziziphus* spp. (Ksiksi *et al.* 2006), and of the exotic *P. juliflora* and *Euclayptus* spp. (El-Keblawy and Ksiksi 2005)through the determination of the effect of forest trees on species diversity and abundance of perennial plants in six forests. The impact of artificial forests on physical and chemical characters of the soil was also evaluated.\n\nThe results showed insignificant variation in species richness and species diversity index among the six studied forests. The effects of type and size of trees grown in the forest trees were significant on all the studied community attributes. All the attributes were significantly greater inside than outside forests cultivated with the native Prosopis cineraria (L.. The role of *P. cineraria* within the natural Arabian peninsula ecology has been well described (Brown 1988).

P. cineraria reproduces both sexually and asexually under natural conditions (Brown 1992). A tight cluster in Oman was shown to be clonally derived, by methods of root excavation and isoenzyme analysis (Brown 1988). Commercial propagators have reported that the species suckers easily, though cuttings do not readily produce roots (Sandison and Harris 1991; Puri and Kumar 1995). Asexual reproduction occurs through root suckers. In low dunes, these can be frequently observed at and near the base of mature trees. The lead author has observed trees to produce a lateral root, 3-4 cm diameter and extending up to 19m from the base of the parent tree, harboring root sprouts. Sightings of living lateral roots were extremely rare, even on apparently shifting sands, but discarded lateral roots rise to the surface in a declining forest.

Pod production in the UAE is highly variable. Fecundity is affected by access to water, such that trees in urban settings typically produce perhaps hundreds times the number of pods observed in trees with less reliable water sources. Under natural conditions, forests have been observed to produce pods annually, but some isolated clusters have been reported to not produce pods over many seasons. One possible hypothesis is that fecundity is affected by tree density and, therefore, competition for water. Hence, the number of pods in a remote cluster would be relative to water availability, rather than to the number of trees.

Prosopis species are typically self-incompatible (Pasiecznik *et al.* 2004; Barrera and Smith 2009), leading to a second hypothesis that isolated tree clusters are asexual clonal colonies, derived from a single tree, and flowers therefore reject pollen from other flowers within the same tree cluster. Pollination occurs via insect vectors, though birds and bats may contribute (Brown 1992). Only a few flowers within each inflorescence can develop into pods due to space, but the other flowers may contribute to reproductive success by attracting pollinators (Koptur 1984) or by rejection of self-incompatible pollen. Pollinators are likely to move among trees within a cluster more frequently than they will move among trees of different clusters. Hence, the frequency of pod production within a tree cluster would be inversely related to the frequency of asexual reproduction among trees. From this hypothesis, a highly isolated cluster of trees would produce many pods if each tree of the cluster had grown from seedlings, and few to potentially no pods if they are clonally derived from one original seedling.

The aim of this study was to determine if observation of seed pod production could be used as a novel method of identifying mode of tree reproduction over a large scale. Some clusters contain many hundreds of trees, but asexual reproduction has been proven only within small clusters of 3-4 trees. If the hypothesis that pod production is related to localized genetic variation is correct, then it would provide an easy method of assessing the genetic base of a forest. Implications for both conservation and agroforestry management will be discussed.

Material and methods

Three locations were identified for this study, termed ‘cluster’, ‘open’, and ‘mixed’. The ‘cluster’ location contains four isolated clusters (Fig 1a) within the Dubai Desert Conservation Reserve.

Clusters 1 and 2 are proximal, their borders separated by 260 m, but the next closest cluster of the species is six kilometers away. They are comprised of 247 and 456 trees respectively. Cluster 3 contains fewer, larger trees, while cluster 4 contains just four trees which might be a natural cluster, or might be an anthropogenically derived group. Structure of all four clusters are described in Gallacher and Hill (2005). The 'mixed' location was chosen through satellite imagery (Google Earth) because it appears to contain many clusters within a broader, possibly open forest (Fig 1b). The 'open' location is a wadi bed (Falaj Al Mualla) that contains trees in a clearly non-clustering distribution. Both the 'open' and 'mixed' locations are within Umm Al Quwain Emirate, and are close to the center of the *ghaf* population within the UAE.

Trees at each location were observed on 3 May 2012 for presence/absence of flowers, and then on 26 June (clusters) and 2 July 2012 (mixed and open) for presence/absence of seed pods. For the latter, a transect line was followed through the forest, and each observed tree was GPS tagged. Trees with many pods were easily detected by sight and, with a little practice, even trees with just a handful of pods could be detected quite readily. It is possible that some trees with just one or a few pods were overlooked.

Results

Flowering was observed to be ubiquitous. Fecundity varied substantially among trees within sites, and appeared to be correlated with quantity of leaf matter, though the relationship was not tested in this study. Trees with extremely minimal vegetation were still observed to produce flowers.

Pod production, however, was strongly related to tree distribution (Table 1), such that trees in open forest always produced pods, while trees in clusters usually did not. No pods were observed in Clusters 1-3, indicating that pollen was incompatible within each of these clusters. In a previous season, authors have observed a single pod growing on a single tree in Cluster 3. This is consistent with the prediction that flowers will usually be pollinated from the same or neighboring trees, but will, on rare occasions, be pollinated from distant trees. Since Clusters 1 and 2 are separated by only 260 meters, pollination between these clusters should be more frequent.

Table 1: Number of trees observed with one or more seed pods, among different classifications of tree distribution.

Category	Location	No. trees observed	No. trees bearing seed pods	Observed trees with pods (%)
Cluster 1	N24.849 E55.700	43	0	0
Cluster 2	N24.846 E55.704	62	0	0
Cluster 3	N24.794 E55.611	23	0	0
Cluster 4	N24.801 E55.623	4	3	75
Mixed	N25.360, E55.800	437	42	10
Open	N25.370, E55.850	22	22	100

The absence of any observed pods suggests not only that each cluster consists entirely of one clonal group of trees, but also that both clusters might be the same clonal group. Cluster 4 consists of just four trees, which might not be a natural cluster. Three of the trees produced pods that were unevenly distributed in clumps within the trees. Hence, by the hypothesis, at least one of these trees was genetically different from the others.

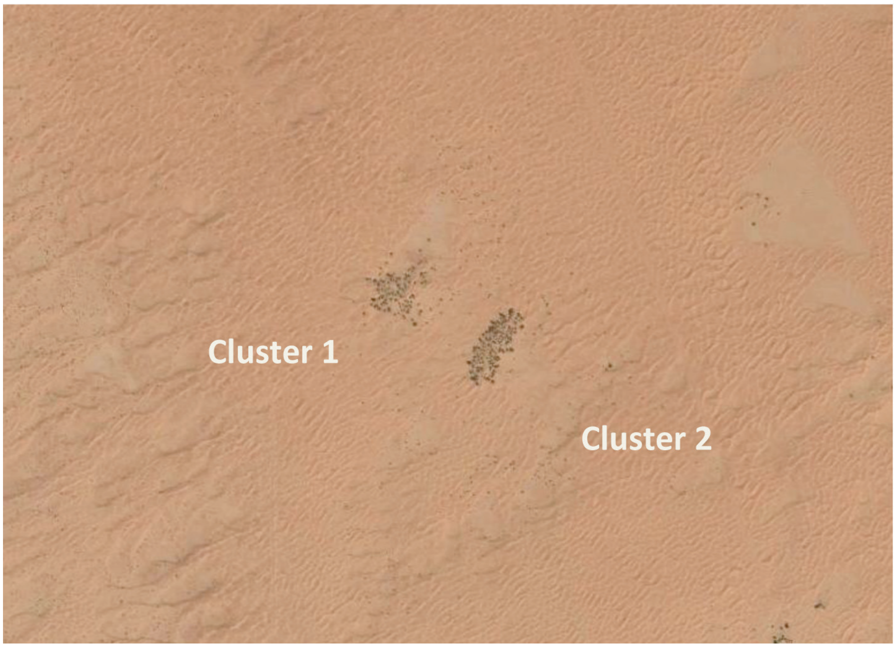

Figure 1a: Two of the four isolated *Prosopis cineraria* clusters observed, containing 247 (cluster 1) and 456 (cluster 2) trees (Gallacher and Hill 2005). All are located within the Dubai Desert Conservation Reserve, United Arab Emirates.

Figure 1b: Observation site for 'Mixed' *Prosopis cineraria* clusters within an open forest (N 25.360, E 55.800), and the 'Open' forest along a wadi bed (N 25.370, E 55.850). The town is Falaj Al Mualla in Umm Al Quwain emirate of the United Arab Emirates. Dark dots within the mixed group are mostly *Prosopis cineraria*, though some on the Eastern edge of the mixed group are *Acacia tortilis*.

Distribution of pods among trees in the 'mixed' forest indicates that the forest is comprised mostly of one clonal cluster, interspersed with smaller, genetically different clusters. Three different patterns of pod distribution were observed:

- A single pod was observed on three trees, each surrounded by many trees devoid of fruit (Fig 2a). This is consistent with the hypothesis that pollination from outside the cluster will occur, but only rarely.
- A single cluster of trees was observed in which approximately half the trees contained a large number of pods, some trees with no pods, and some trees of low fecundity (Fig 2b). This pattern suggests the presence of several genetically distinct individuals, some of which have also reproduced asexually.
- Five locations were observed with multiple pod-bearing trees, usually with a small number of pods but occasionally with many. This is explained by the presence of one genetically different tree or tree cluster. The distinct cluster in Fig 3 illustrates a cluster within the larger cluster. It has a diameter of 33 meters, and is 72 meters from its nearest neighbor. Three of its 19 trees contained a small number of pods, while the rest were barren; indicating that some outcrossing had occurred with neighboring clusters but that most pollination was incompatible.

Discussion

Observed pod distributions in this study can be explained through floral self-incompatibility and asexual reproduction to produce clonal clusters. Sexual reproduction is dominant in open forests that do not exhibit clustering, but asexual reproduction is dominant in isolated clusters such as those of the Dubai Desert Conservation Reserve, in which a single genotype may produce hundreds of trees. The research indicates that asexual reproduction is far more common than previously supposed. It also indicates that the species switches almost completely from one mode of reproduction to the other, depending on the habitat. Forests in low dunes are characterized by clustering and a lack of pod production, while forests growing on a gravel substrate are pod-producing and distributed as open forest.

The authors postulate that *P. cineraria* seedlings only rarely, if ever, succeed to establish in a low dune habitat, and instead require a gravelly substrate. Conversely, the lateral roots that enable asexual reproduction occur only in sandy substrate, probably due to the mechanics of lateral growth in the looser medium. Hence, clusters 1-3 were each derived from a single seedling that succeeded to grow on inter-dune gravel substrate, but they then reproduced asexually to produce clonal clusters on sand substrate, containing hundreds of individual tree clones. In the mixed forest, many seedlings have become established on the sandy/gravel substrate (Fig 2, East) but only one or a few have spread asexually to become established in the low dunes to the West. Numerically, most of the eastern trees and all of the western trees have been produced asexually.

Sustainability

Concerns about natural population sustainability of ghaf in the Arabian peninsula have previously focused on minimal observed regeneration of the species (Brown 1992; Gallacher and Hill 2005; Abdel Bari *et al.* 2007). Low regeneration is usually attributed to heavy grazing, which impacts

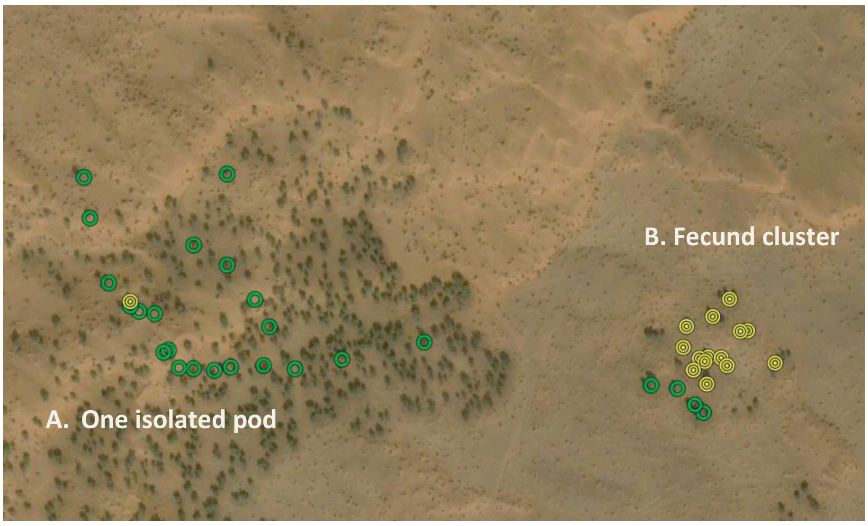

Figure 2: Two patterns of pod distribution within the 'Mixed' group, showing trees that were observed with (yellow) and without (green) pods. Trees lying on the path between green circles were also observed to be without pods.

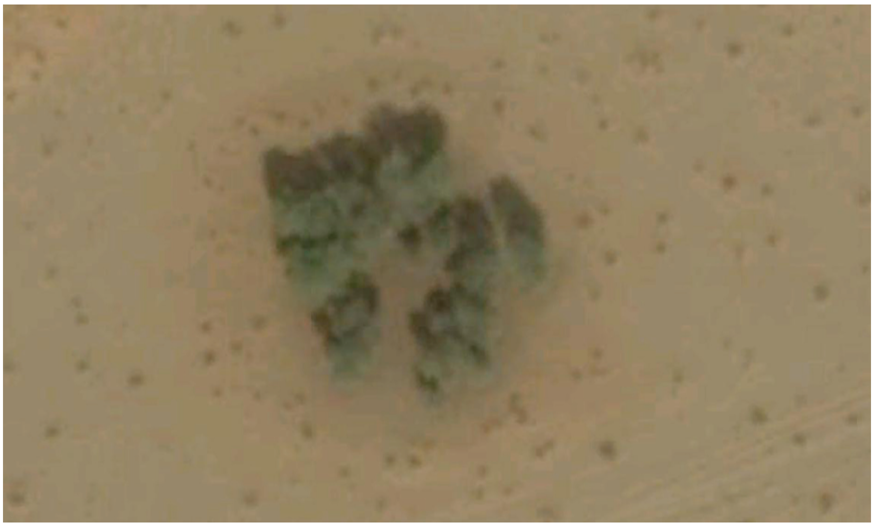

Figure 3: A single cluster of 19 trees (N25.348 E55.789) located within the 'mixed' forest. Three of the trees contained a small number of pods, while the other 16 contained no pods. Note that the darker is shadow on sand substrate, while the lighter is tree canopy.

perennial seedlings more than annuals (Gallacher and Hill 2008). This study's inference of widespread asexual reproduction has both positive and negative consequences for this discussion. Negative, because of low genetic diversity, and positive, because afforestation is relatively easily managed.

Natural genetic diversity is much smaller than the number of individual trees would imply, by perhaps two to three magnitudes. Nevertheless, the natural population in the UAE, is large, and probably still contains thousands of unique genotypes. Genetic diversity is substantial in Rajasthan , India (Rawat *et al.* 2007; Sharma *et al.* 2011)fodder, food and\nmedicinal uses. Some remarkable features are observed\nin the form of phenotypic variation in various populations\ninhabiting different regions of the Indian desert.\nTo asses these variations male meiotic studies were conducted\nin ten different accessions collected from four\nproviences of Rajasthan, India. Analysis of data on chromosome\nassociations, chiasma frequency and their distributions\npattern concluded that the somatic chromosome\nnumber of P. cineraria is 2n = 2x = 28. The complete\nabsence of accessory chromosomes (B, suggestive of a species that is adaptive to a variety of conditions. It is difficult to imagine that significant genetic erosion is occurring in natural populations, unless specific habitats that facilitate specific genotypes are being eroded.

A realistic discussion of genetic diversity in Arabia must necessarily include the extensive artificial plantations of the species in afforestation projects and roadside plantations, dating mainly from the 1970s and 1980s (Kiriiwa *et al.* 2002). Most trees were planted in regions outside the natural range of the species, but most, particularly roadside plantings, have been sustained through groundwater irrigation. The number of artificially placed *P. cineraria* trees in the UAE far exceeds the natural population. The authors of this paper do not know the genetic origin of these trees, but due to the prevalence of Indian companies willing to provide seed, there is a good chance many are from the Thar Desert region. This raises two questions; are Arabian populations genetically differentiated, and if so, are Arabian populations being genetically eroded?

Rehabilitation

The high frequency of asexual generation in the species is encouraging for rehabilitation, since a highly degraded area might recover rapidly with appropriate herbivore protection. Rapid recovery from rootstock has been reported in other species of the same habitat (Gallacher and Hill 2006)2006. There is some indication that, even in natural systems, regeneration of the species occurs in waves, triggered perhaps by a series of high rainfall seasons, or a chance reprieve from grazing pressure. Hence, it should be possible to regulate the rate of asexual forest regeneration by providing a physical barrier to grazing during favorable seasons.

Pod production

Seed pods have significant commercial and ecological significance. They are a food source for a wide variety of native herbivores (Brown 1988), and immature pods have been routinely fed to livestock (Pasiecznik *et al.* 2004) and, historically, the indigenous *Bedu* (Jongbloed *et al.* 2003). Thus, there is commercial, and possibly ecological, value in raising the frequency of cross-pollination among trees, by interspersing genetically different trees among an asexual cluster.

Conclusions

Asexual reproduction in *Prosopis cineraria* in the UAE appears to be very common in sandy substrate, and ubiquitous in low dunes, producing tight clusters ranging from two, to hundreds of individual trees. In contrast, sexual reproduction is ubiquitous on gravel substrates, where clusters are not observed. Asexual clustering distribution on this scale might be limited to the Arabian Peninsula, though available literature is insufficient on this issue. Conservation efforts should account for both forms of reproduction. Agroforestry could be enhanced through artificial cross-fertilization within asexual clusters to promote pod production.

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Relationship between the growth of *Tamarix ramosissima* and morphology of nebkhas in oasis-desert ecotones

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Abstract

Nebkhas are mounds composed of wind-borne sediment that accumulate around shrubs. Plants play very important roles on forming the morphology of nebkhas in arid and semi-arid areas. The growth status of natural vegetation in oasis-desert ecotones of northwest China is mostly related to the groundwater. The present study chose three areas with significantly different groundwater depths (14.9 m, 11.7 m, and 7.2 m) in the Qira oasis-desert ecotone located at the southern rim of the Taklimakan Desert, China. A total of 100 relatively independent *Tamarix ramosissima* nebkhas were randomly selected to investigate the plant morphometrics and the nebkhas morphology, and their mutual relation was analyzed. The results showed that with decrease in groundwater depth, the height of *Tamarix ramosissima* had no significantly change. However, the total number of branches and crown area were significantly increased. In areas with 14.9 m, 11.7 m, and 7.2 m groundwater depth, the proportion of new branches to total branches in the current year was 32.2%, 38.7%, and 53.7%, and the proportion of new grown biomass was 3.6%, 5.9%, and 14.3%, respectively. The volume of nebkhas increased significantly with increased crown area, and the crown area was closely related to the total number of plant branches. There was a high correlation between the length and width of nebkhas, basal area and height, as well as basal area and volume. The nebkhas with distinctive deposition tails along the dominant wind direction resulted from strong wind-blown sand activity under a single wind direction environment. Thus the morphological adaptive mechanism of *Tamarix ramosissima* nebkhas can be attributed to the available groundwater depth. In the area with about 15 m groundwater depth, the proportion of dead branch significantly increased and the volume of nebkhas significantly decreased. This indicates the degradation of *Tamarix ramosissima* and the disappearing tendency of nebkhas under the influence of such groundwater depth.

Introduction

Nebkhas are mounds composed of wind-borne sediment that accumulate around shrubs (Hesp 1981; Nickling *et al.* 1994). Nebkhas are widely distributed in arid and semi-arid areas all over the world. They are attracting increased research attention due to their significance in terms of land deterioration (Zhu *et al.* 1994; Tengberg 1995; Wang *et al.* 2006). Shrubs play an important role in shaping the morphology of nebkhas (Tengberg *et al.* 1998; Nield *et al.* 2008). They affect not only the formation of nebkhas by covering ground surface, breaking wind force and blocking sand grains (Nickling *et al.* 1994), but also the morphology of nebkhas.

There are a variety of plant types that form nebkhas. Different vegetation species exhibit different growth form and therefore greatly influence nebkhas morphology (Hesp *et al.* 2000). Even for the same plant, the nebkhas with different morphologies were observed as well in different growing stages (Li *et al.* 2007a). Tamarix spp. is mainly distributed in desert, semi-desert and grassland in Asia, Africa and Europe (CAS 1990). In the arid region of northwest China, these plants are mainly distributed in the alluvial fan at the foot of mountain, alluvial river terraces and oasis-desert ecotones (Qong *et al.* 2002).

As the key species in the Central Asian desert ecosystem, the *Tamarix* spp. is characterized by wide distribution and strong adaptability (Yin *et al.* 1995). Many studies have focused on their physiological and ecological adaptation (Brotherson *et al.* 1986; Gries D *et al.* 2003; Xu *et al.* 2007; Thomas *et al.* 2008). In recent years, *Tamarix nebkhas* in northwest China have attracted wide attention for their significance in ecological security of the oasis and as an important indicator of change in desert environment. Numerous researches related to Tamarix nebkhas have been carried out, including Tamarix nebkhas distribution and their development (Mu *et al.* 1994; Li *et al.* 2007a), formation and their internal stratification features (Qong *et al.* 2002; Xia *et al.* 2004), effect of wind current on nebkhas' morphology (Li *et al.* 2007b), spatial heterogeneity in desert-oasis ecotones (Liu *et al.*, 2008) and as indicators of environmental degradation (Wang *et al.* 2008).

Tamarix ramosissima, as a phreatophyte, relies mostly on groundwater for survival (Xu *et al.* 2006; Frank *et al.* 2008). This plant has a dense, multi-branching growth habit. When the groundwater depth is down to a certain degree, it reacts by reducing the number of newly emerging branches and increasing the number of dead branches for that year (Zhao *et al.* 2004). Consequently, the configuration of *Tamarix ramosissima* and the corresponding morphology of nebkhas are affected. However, studies on the growth of *Tamarix ramosissima* as affected by change in groundwater depth and consequent nebkha morphology and their relationships are few.

In this study, three sampling areas with significantly different groundwater levels were selected in the Qira oasis-desert ecotone located at the southern rim of the Taklimakan Desert. A total of 100 relatively independent *Tamarix ramosissima* nebkhas were randomly selected and analyzed to investigate the plants morphometrics and the nebkhas morphology, and their mutual relation under the influence of the depth of groundwater. The objective of this study is help to understand the interactions between *Tamarix ramosissima* growth and wind-blown sand accumulation in aeolian environment and provide information to decision makers for improving groundwater management practices in the oasis-desert ecotones.

Study area and methods

The study area (Fig.1) was in the west foreland of the Qira oasis, also known as Cele. Qira is located at 37°01′N and 80°48′E, at an elevation of 1365 m a.s.l. on the southern rim of the Tarim basin in the Xinjiang Uyghur Autonomous Region, China. The surface relief of the western section of the oasis inclines toward the northwest. The extremely continental climate in Qira is characterized by cold, dry winters and hot, dry summers. The average annual temperature is 11.9 °C. The monthly average temperatures are -5.8 °C for January and 25.1 °C for June. The highest recorded temperature is 41.9 °C and the lowest -23.9 °C. The climate is extremely dry with an annual precipitation of 35.1 mm and an annual evaporation of 2595.3 mm. Aeolian sandy and brown desert soils are dominant, with silt fraction of the soil exceeding 87% (Bruelheide *et al.* 2010). The prevailing wind directions are W and WNW and the frequency of sand moving winds from both directions accounts for more than 80% of the annual total (Xing *et al.* 2008). The strong wind and blown sand activities occur in April, May, June and July. The drift potentials of these four months account for 14.1%, 22.8%, 18.4% and 18.0% of annual total, respectively (Wang *et al.* 2011).

The vegetation forms are monotonous with simple community structures. *Tamarix ramosissima* Ledeb., *Alhagi sparsifolia* Shap. and *Karelinia caspica* Less. are the constructive species. Annual precipitation is insignificant for plant growth, the perennial species are exclusively dependent on groundwater. The groundwater depth has important implication for the construction and distribution of natural plant communities (Li *et al.* 2010). However, water quality has no serious effect on the rejection capability of *Tamarix ramosissima* (Dai *et al.* 2009). As a salt-accumulating shrub, *Tamarix ramosissima* is widely distributed in this area, its lignified limbs as well as soft anabolic branches and leaves can block wind and accumulate sands significantly. It forms nebkhas with different sizes in the ecotone and becomes the natural barrier for protecting the Qira oases. Under impact of human activities, especially the fall of groundwater table due to the overexploitation in nearby oases, the desertification problem has accentuated in this area. The manifestations include the decreased size of ecotone areas, the continuously decline of vegetation, the expanding denudation of ground and occurrence of wandering dunes (Bruelheide *et al.* 2003).

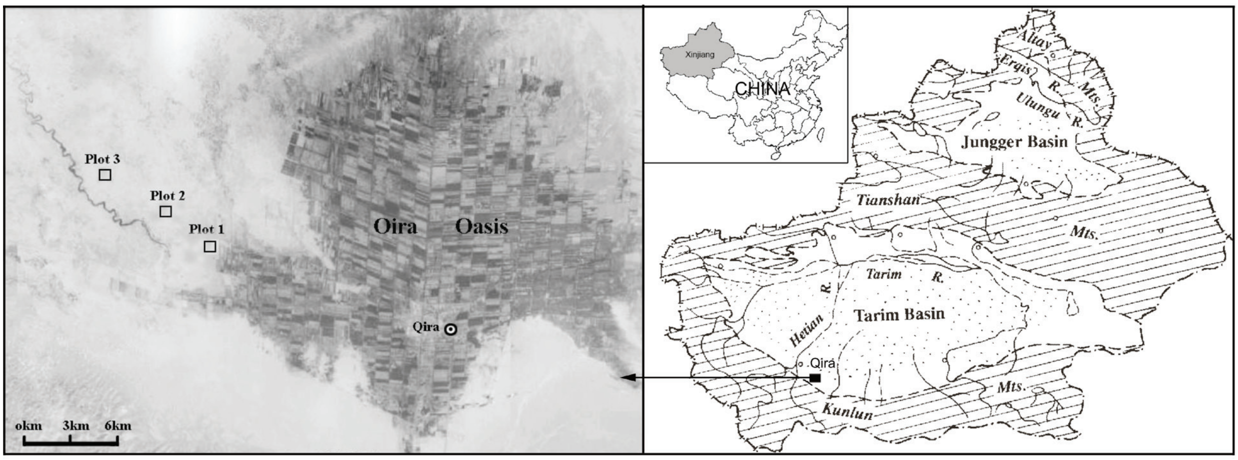

Figure 1: Sets of observation sample plots.

The groundwater depth in the Qira oasis-desert ecotone ranges from 6 m to 15 m from outside to inside. Three sample plots with 500×500 m were set along the profile with significant changes in groundwater depth (Fig. 1). The groundwater depth in each sample plot was measured at the beginning of each month. The plant community type and species composition, the landscape characteristics and amounts of surveyed nebkhas in the sample plots are given in Table 1. Within each plot, 100 relatively independent *Tamarix ramosissima* nebkhas were randomly chosen near the observation wells. The geographic coordinates were recorded and morphometric measurements were performed for each nebkha. The morphological parameters included the length L (along the dominant wind direction), width W (perpendicular to the dominant wind direction), windward slope angle α, leeward slope angle β, length of windward long axis La, length of leeward long axis Lb, windward slope length La′, leeward slope length Lb′, as well as relative heights in the eastern direction HE, southern direction HS, western direction HW and northern direction HN (Fig. 2). The height of a nebkha H was calculated based on the average value of the relative heights in the four directions.

The length-to-width ratio of a nebkha L/W was used to measure its tensile strength along the wind direction, where a higher ratio indicates a longer relative tensile strength. Lb′/La′ is the ratio of the leeward slope length and the windward slope length, where a higher ratio indicates a clearer sand tail. The basal area S1 and volume V1 of a semi-elliptical nebkha with a windward slope basically symmetrical to the leeward slope was calculated based on the following formulas:

$$S_1 = \frac{1}{4}\pi WL \,; \quad V_1 = \frac{1}{6}\pi WHL$$

The basal area S2 and volume V2 of nebkhas with a clear sand tail whose leeward slope length is more than windward slope length was calculated based on the following formulas:

$$S_2 = \frac{1}{2}\pi L_a W + \frac{1}{2}L'(L_b - \frac{H_E}{\tan\beta_1}) \,; \quad V_2 = \frac{1}{3}\pi L_a WH + \frac{1}{6}L'(H - H_E)(L_b - \frac{H_E}{\tan\beta_1})$$

where β1 is the slope angle in the leeward position with the strongest change, and L′ refers to the base length of an isosceles triangle connected with an ellipse on the basal area of nebkhas. The formula of L′ is:

$$L' = W\sqrt{1 - \left(\frac{H_E}{L_a \times \tan\beta_1}\right)^2}$$

The configuration parameters of the *Tamarix ramosissima* corresponding to all 100 selected nebkhas were measured. They include the shrub height h, length l (along the dominant wind direction), width w (perpendicular to the dominant wind direction), number of old branches above ground Bo, total number of new branches in that year Bn (number of new branches only born in the shrub base is represented by Bn′), and number of dead branches Bd. The crown area C is calculated by the length and width of shrub:

$$C = \frac{1}{4}\pi lw$$

The total number of branches N was calculated based on the number of old, new and dead branches:

$$N = B_o + B_n + B_d$$

The new branches ratio Rn is the percentage of new branches in that year:

$$R_n = \frac{B_n}{N} \times 100\%$$

The new basal braches ratio Rb was the percentage of new branches growing at the base of the total new branches aboveground in that year:

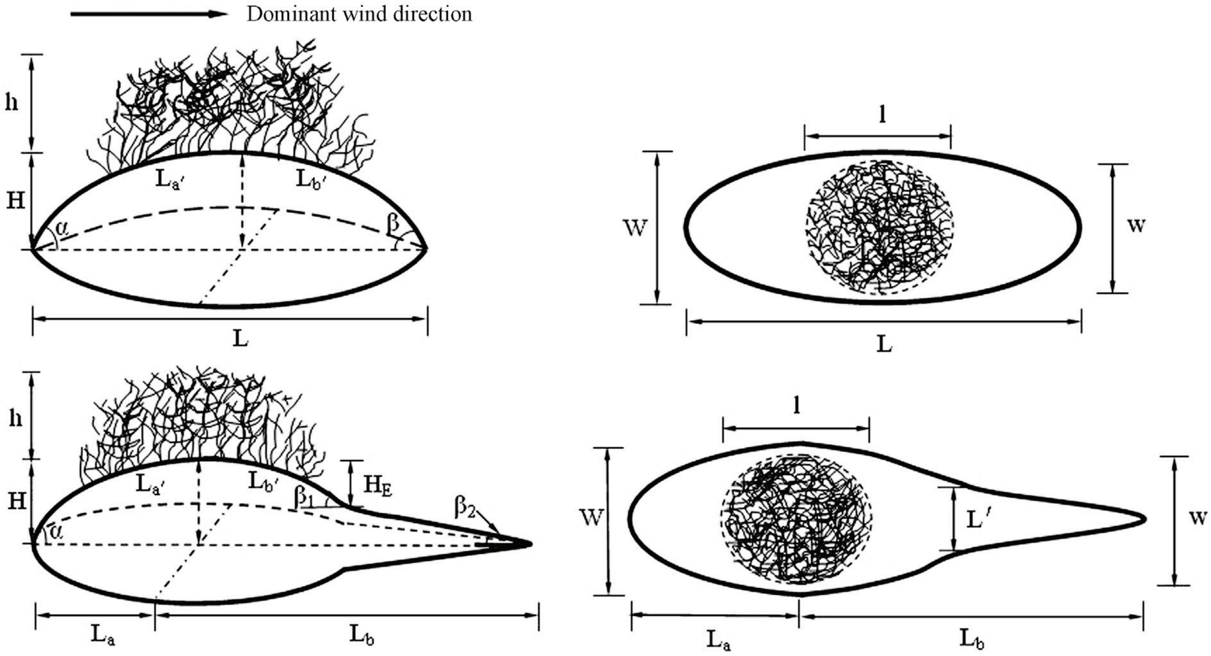

Figure 2: Schematic diagram illustrates the morphometers of nebkhas.

Table 1: Groundwater depth and landscape features in the study sites

Plot	GWD depth (m)	Coordinates of well sites	Alt. (m)	Plant community & species composition	Landscape characteristics	% of surveyed Nebkhas
1	14..9±0.20	37°01’02’’N 80°43’11’’E	1363	*Al* dominant community: *Al* + *Ka* + *Ta* + *Sc*	Vegetation coverage from 25% to 30%; plants distributed uniformly; the ground surface in a semi-mobile state.	38
2	11.7±0.09	37°01’47’’N 80°42’32’’E	1355	*Al–Ta–Ka* community: *Al* + *Ta*+ *Ka*+ *Sc*	Vegetation cover from 15% to 20%; plants distributed unevenly; herbaceous nebkhas present; bare sand occupies about 50% area.	30
3	7.2±0.07	37°02’31’’N 80°40’51’’E	1344	*Ta* dominant community: *Ta*+ *Ha*	Vegetation cover is less than 10%; individual nebkhas tall, some having clear sand tail; bare sand is > 80%.	32

Note: GWD (groundwater depth) is an average value for 12 months ± SD. *Al*, *Alhagi sparsifolia*; *Ka*, *Karelinia caspica*; *Ta*, *Tamarix ramosissima; Sc*, *Scorzonera divaricata*; *Ha, Halogeton glomeratus*

$$R_b = \frac{B_n'}{B_n} \times 100\%$$

For each *Tamarix ramosissima* shrub, both old and new branches were categorized based on their length and stem thickness. The sample branches were taken to the laboratory, weighed and dried at 80 °C for 48 h for calculating the aboveground biomass of the shrub P and the new biomass in that year P′. The software of Origin 8.0 and SPSS 16.0 were used to conduct the descriptive statistics and variance analyses on the shrub as well as the morphological features of nebkhas. Correlation and regression analyses were also performed in terms of the morphological parameters of nebkhas, as well as all morphological parameters of the shrub to reveal the relationship between the morphology of the two as affected by the groundwater depth.

Results and discussion

Morphological features of *Tamarix ramosissima*

The results show that the average heights of *Tamarix ramosissima* in all plots was around 2.4 m without any significant difference. However, the crown diameter varied greatly from 1.6 m to 13 m. Along the sequence from plot 1, to plot 2 and plot 3, the morphological parameters increased significantly. The average groundwater depths in the three sampled plots was 14.9 m, 11.7 m and 7.2 m, while the average crown area of *T. ramosissima* was 28m2, 42 m2 and 54 m2 respectively. The total number of shrub branches, new branch ratio, new basal branch ratio, aboveground biomass and new biomass in that year also increased significantly ($P<0.05$) as the water table depth decreased. In contrast, the dead branch ratio decreased from 22.4% in plot 1 to 9.2% in plot 3 (Table 2). The crown area closely related to the total number of branches (Fig. 3). According to previous researches, all perennial plants in the transition zone between oases and desert in arid area must have sufficient access to groundwater to ensure long-term survival (Thomas *et al.* 2006; 2008). When groundwater table declines to some degree and water stress occurs, water supply to some parts of the plant is reduced causing withering of some branches. In contrast, the appropriate groundwater depth helps generate new branches and increase the biomass. A substantial increase in new basal branches changes the internal structure of shrubs, while other new branches change the out features, thereby changing the overall morphology of shrubs.

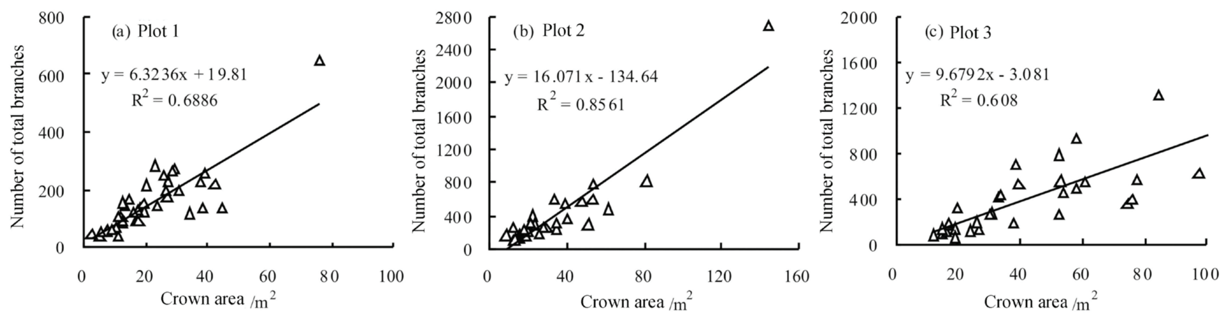

Figure 3: Relationship between the crown area and total number of branches of *Tamarix ramosissima.*

Morphological analysis of the nebkhas

The heights of nebkhas in the study area ranged from 0.3 m to 4 m, and their lengths from 1.4 m to 40 m. The average height of nebkhas was 0.92 m, 1.41 m and 1.80 m, and the volume was 18.96 m3, 56.50 m3 and 82.07 m3 , respectively, for plots 1, 2 and 3 (Table 3). The average values of the other morphological parameters increased significantly from plot 1 to plot 3 ($P < 0.05$), indicating an increasing trend in both horizontal component size and height of nebkhas as the groundwater depths declined (Table 3). On the other hand, the increasing trends of L/W and Lb′/La′ from plot 1 to plot 2 and plot 3 indicated that the nebkhas considerably stretch along the dominant wind direction, accompanied by a gradual formation of sand tail with a clear outline.

The correlation analysis reveals a strong relationship among the morphological parameters of nebkhas except for L/W and Lb′/La′ (Table 4). The length of nebkhas is significantly correlated to its width. Plot 3 shows a significant quadratic function relationship whereas plots 1 and 2 maintain stable linear monotonous increasing trends (Figure 4a to 4c). Except for the length and height of nebkhas in plot 3, the correlation coefficient on the parameters related to horizontal component scale (length, width, and basal area) in all three plots as well as between the horizontal component and height of nebkhas are significantly correlated at $p=0.01$. Especially, the width of nebkhas is most closely correlated to their basal area (R2≥0.903) (Table 4). The height of nebkhas in each plot increased in a logarithmic function with increased basal area (R2≥0.6207). The increase slows down when the basal area is around 50 m2 (Figure 4d to 4f). The volume of nebkhas in each plot increased according to the exponential function with the increase of basal area (R2≥0.8793) (Figure 4g to 4i). The morphological parameters L/W and Lb′/La′ were significantly correlated at $p=0.01$. This indicates that the tensile deformation of a nebkhas changes along the prevailing wind direction in proportion to the asymmetric development of the nebkha in the windward and leeward side.

Relationship between *Tamarix ramosissima* and nebkhas morphology

The statistical analysis shows a strong correlation among the morphological parameters of nebkhas and *Tamarix ramosissima*, except for L/W and Lb′/La′ (Table 5). The shrub crown area is most closely correlated to each morphological parameter of the nebkhas. The volume of nebkhas in the three plots increased with the crown area followed by an exponential function (R2≥0.8193) (Fig. 5), and the crown area linearly increased with total number of branches (R2≥0.608) (Fig. 3). The correlations between the height of *Tamarix ramosissima* and all morphological parameters of nebkhas are relatively weak, reflecting the inherent ecological characteristics of *Tamarix ramosissima*. Although the height and volume of nebkha increased with continuous sand accumulation, the plant height aboveground always remained relatively stable. This phenomenon embodies the growth characteristic as in the idiomatic expression, "As water rises, the boat rises with it". All morphological parameters of nebkhas in the three plots showed strong correlation with the total number of branches of *Tamarix ramosissima* and the number of new branches in that year, indicating an obvious interaction between nebkhas and plant growth. The low or no correlation between L/W, Lb′/La′ and other shrubs parameters reveal that the stretching of nebkhas along the wind direction and the occurrence of a sand tail may be mostly restricted by the wind regime and sand source but not the morphology of plants. The height, basal area and volume of nebkhas are largely restricted by the growth conditions and morphological features of *Tamarix ramosissima*.

Table 2: Statistical analysis of the morphological parameters of *Tamarix ramosissima*

Plot		h (m)	l (m)	w (m)	C (m^2)	N (pc.)	Rn (%)	Rb (%)	Ro (%)	P (kg)	P′ (kg)
1	Min. Value	1.00	1.81	1.68	3.04	39.00	12.20	0.00	5.60	0.26	0.03
	Max. Value	3.58	9.30	10.40	96.72	648.00	53.10	51.00	56.10	62.67	2.05
	Mean ± Std Error	2.44±0.09	4.99±0.26a	5.13±0.27a	28.06±2.92a	159.11±17.45a5a	32.18±1.42a	16.58±2.31a	22.38±1.79a	15.19±2.58a	0.54±0.07a
2	Min. Value	1.68	3.25	3.15	10.24	91.00	16.00	4.40	3.90	4.60	0.30
	Max. Value	3.22	14.85	12.40	184.14	2688.00	60.10	65.10	59.70	289.96	15.29
	Mean ± Std Error	2.36±0.06	5.98±0.44ab	6.26±0.40b	42.09±6.37b	396.37±86.83b	38.70±2.01b	26.43±3.06b	25.18±1.84a	41.13±10.68b	2.43±0.54a
3	Min. Value	2.05	3.35	4.15	15.41	66.00	15.30	0.00	0.00	3.42	0.15
	Max. Value	3.14	12.65	13.15	128.76	1318.00	83.30	75.00	25.90	131.48	29.22
	Mean ± Std Error	2.54±0.05	6.96±0.44b	7.25±0.39b	54.44±5.75b	410.56±56.03b	53.67±2.84c	41.88±3.21c	9.23±1.00b	47.99±7.35b	6.85±1.36b

Note: Values (Mean ± SE) h, shrub height; l, length; w, width; C, crown area; N, total number of branches; Rn, % of new branches; Rb, % of new branches born at the base accounting for all new branches; Rd, % of dead branches; P, aboveground biomass of *Tamarix ramosissima*; P′, new biomass in that year.

Table 3: Statistical analysis of the morphological parameters of nabkahs

Plot		H (m)	L (m)	W (m)	S (m^2)	V (m^3)	L/W	Lb′/ La′
1	Min. Value	0.26	1.40	1.40	1.50	0.30	0.70	1.00
	Max. Value	2.33	15.50	13.30	149.00	201.60	2.70	3.00
	Mean ± S E	0.92±0.07a	5.93±0.45a	5.02±0.32a	25.53±4.01a	18.96±5.24a	1.19±0.06a	1.32±0.08a
2	Min. Value	0.62	2.95	3.45	8.00	4.20	0.80	1.00
	Max. Value	3.82	28.90	15.60	244.60	562.30	2.50	4.00
	Mean ± SE	1.41±0.12b	9.71±0.95b	6.67±0.47b	50.56±8.46b	56.50±18.80b	1.43±0.06b	1.70±0.12b
3	Min. Value	0.70	4.20	3.30	10.40	4.20	0.90	0.90
	Max. Value	3.21	39.05	13.30	255.30	291.60	4.70	16.80
	Mean ± SE	1.80±0.19c	12.01±1.29b	7.87±0.47b	68.97±9.12b	82.07±12.86c	1.52±0.13b	2.21±0.51b

Note: Values (Mean ± SE) H, nabkah height; L, nabkah length; W, nabkah width; S, nabkah basal area; V, nabkah volume; La′, windward slope length; Lb′, leeward slope length.

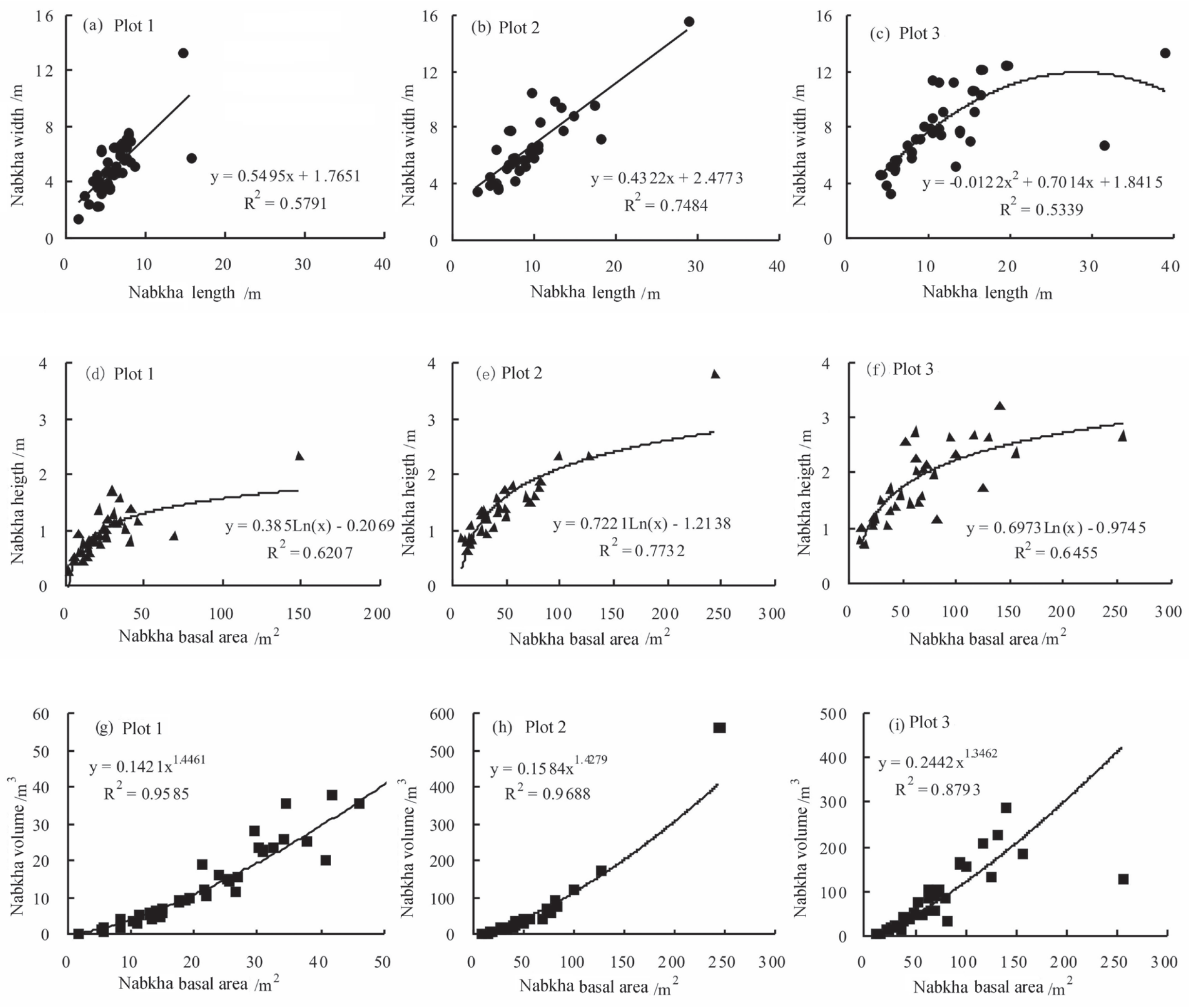

Figure 4: Relationship among the morphological parameters of nebkhas in the three sample plots

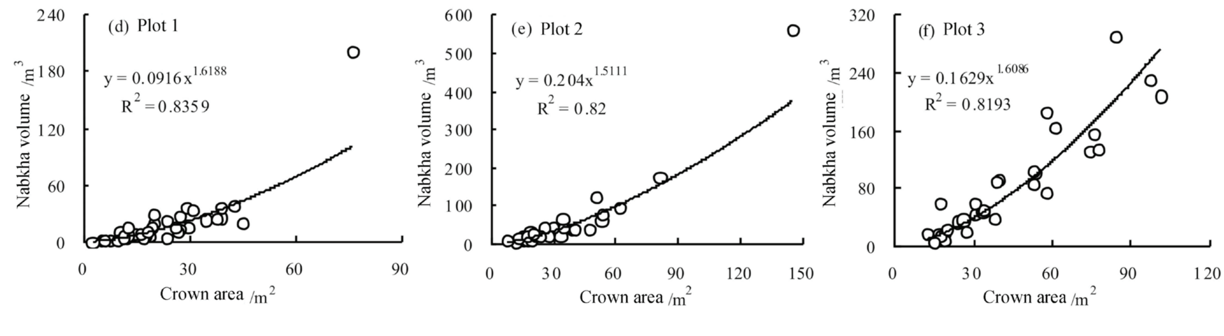

Figure 5: Relationship between the crown area of *Tamarix ramosissima* and the volume of nebkhas

Table 4: Correlation analysis among the morphological parameters of nebkhas

Plot	Parameters	H	L	W	S	V	L/W	L_b'/L_a'
Plot 1	L	0.686**	1					
	W	0.841**	0.761**	1				
	S	0.771**	0.868**	0.909**	1			
	V	0.783**	0.702**	0.862**	0.952**	1		
	L/W	0.023	0.570**	-0.076	0.194	0.018	1	
	L_b'/L_a'	-0.040	0.196	-0.126	-0.003	-0.031	0.543**	1
Plot 2	L	0.891**	1					
	W	0.948**	0.865**	1				
	S	0.959**	0.938**	0.942**	1			
	V	0.903**	0.848**	0.847**	0.953**	1		
	L/W	0.321	0.660**	0.230	0.393*	0.299	1	
	L_b'/L_a'	0.218	0.463**	0.182	0.202	0.108	0.720**	1
Plot 3	L	0.435*	1					
	W	0.870**	0.615**	1				
	S	0.716**	0.828**	0.903**	1			
	V	0.883**	0.417*	0.893**	0.764**	1		
	L/W	-0.050	0.787**	0.067	0.330	-0.054	1	
	L_b'/L_a'	0.117	0.801**	0.272	0.597**	0.016	0.650**	1

Note: * 0.05 significance level; ** 0.01 significance level; the meaning of other letters in head line is revealed in the notes of table 3.

Table 5: Correlation analysis between morphological parameters of *Tamarix ramosissima* and nebkhas

Plot	Parameters	H	L	W	S	V	L/W	L_b'/L_a'
Plot 1	h	0.464**	0.411*	0.509**	0.350*	0.271	-0.004	-0.062
	l	0.702**	0.774**	0.864**	0.773**	0.653**	0.107	-0.104
	w	0.768**	0.736**	0.918**	0.805**	0.725**	-0.015	-0.144
	C	0.750**	0.768**	0.930**	0.877**	0.809**	0.021	-0.104
	N	0.830**	0.725**	0.867**	0.878**	0.880**	0.043	-0.057
	Bn	0.775**	0.684**	0.845**	0.867**	0.880**	0.015	-0.067
Plot 2	h	0.565**	0.557**	0.532**	0.549**	0.529**	0.218	0.137
	l	0.919**	0.864**	0.937**	0.933**	0.877**	0.267	0.154
	w	0.879**	0.778**	0.926**	0.861**	0.757**	0.165	0.114
	C	0.930**	0.859**	0.935**	0.956**	0.927**	0.240	0.117
	N	0.845**	0.780**	0.814**	0.884**	0.945**	0.191	0.089
	Bn	0.791**	0.727**	0.759**	0.813**	0.874**	0.160	0.104
Plot 3	h	0.263	0.207	0.368*	0.253	0.258	0.048	0.000
	l	0.835**	0.292	0.776**	0.607**	0.876**	-0.122	-0.100
	w	0.814**	0.633**	0.945**	0.892**	0.810**	0.089	0.377*
	C	0.856**	0.448*	0.886**	0.770**	0.914**	-0.042	0.103
	N	0.841**	0.260	0.673**	0.495**	0.802**	-0.072	-0.086
	Bn	0.764**	0.141	0.530**	0.327	0.673**	-0.106	-0.192

Note: * 0.05 significance level; ** 0.01 significance level; the meaning of other letters in head line is revealed in the notes of table 2 and table 3.

General discussion

The annual precipitation in the Qira oasis-desert ecotone is around 30 mm. However, there is no severe water stress for several desert plants including *Tamarix ramosissima* throughout an entire growing season (Gries *et al.* 2003; Zeng *et al.* 2009; Thomas *et al.* 2006). The findings show that these plants are inclined to use groundwater. Xu *et al.* (2006) also came to the same conclusion on water-use strategy of this species in the southern rim of Gurbantonggut desert in northwest China. In the current study area, plots 1 to 3 with groundwater depths 14.9 m to 7.2 m are located further away from the oasis, while intensity of sand activities are increasing corresponding to the decrease of vegetation cover. However, the crown breadth, total number of branches, new branch ratio in that year and new growing biomass of the shrub increased significantly, while the dead branch ratio decreased relatively. It suggests that the groundwater depth is more closely related to the survival and growth of *Tamarix ramosissima* exposed to windblown sand interferences. The previous study on the *Tamarix* community in the Ejina oasis in the northwest China showed that combining the dead branch ratio with the new growing biomass in a year is a more suitable method for evaluating desertification degree (Zhao *et al.* 2004). Our findings agree with this view.

Strong correlations have been reported among morphological parameters of nebkhas, such as between the length and width of nebkha, the height and horizontal component, etc. (Tengberg *et al.* 1998; Liu *et al.* 2008). The current study shows that all morphological parameters of nebkhas generally show strong correlations. However, this correlation is weak in plot 3, mainly because the nebkhas there have a strong tensile deformation accompanied by a clear sand tail along the prevailing wind direction that obviously influences vertical and horizontal component size and their relationships. The wind regime in the study area is dominated by singular wind direction (W and WNW); meanwhile wind-blown sand activity in plot 3 is most strong for sparse vegetation, than followed by plot 2 with 15-20% vegetation cover and plot 3 with 25-30% coverage. The increasing tendency of morphological parameters L/W and L_b'/L_a' from plot 1 to plot 3 should be attributed to the wind regime in the area and increasing intensity of wind-blown sand activities.

The formation of nebkhas is controlled by sand source supply, plants that can effectively capture sand materials and wind force capable of eroding and transporting sand materials (Hesp 1981). He *et al.* (2003) suggest that proper aeolian sand burial can induce the plants to grow new branches and accumulate biomass, thus affecting the morphology of nebkhas in turn. However, a prerequisite for maintaining the survival and normal growth of plants is water supply. The Qira oasis-desert ecotone has rich sand source, it does not lack effective wind force capable of eroding and transporting sand materials as well, and in-situ sand movement occurs frequently. Even in the plot 3 near the Qira oasis with vegetation cover of 25-30% wind blown sand activities were observed frequently as well (Yang 2011). Consequently, *Tamarix ramosissim* grows and develops to form shrubs with a certain crown breadth by initially relying on groundwater, and then by blocking blown sand to form nebkhas. The shrubs with larger crown breadths can capture more sand materials and lead to aeolian sand accumulating on the shrubs continuously, which in addition to proper groundwater depth can promote the growth and development of *Tamarix ramosissim.* When the groundwater level drops to a certain degree, the shrubs give up the growth, the corresponding nebkhas stop growing and then are eliminated by wind erosion. In the current study area, the dead branch rate of *Tamarix ramosissima* significantly increased and the volume of nebkhas significantly decreased in plot 1, which indicates the degradation of the shrub and the disappearing tendency of nebkhas under about 15 m groundwater depth.

Conclusions

The survival of *Tamarix ramosissima* in oasis-desert ecotone is closely related to groundwater. Their growing status can be reflected by new growing biomass in a year and by comparing the number of new and dead branches. As the groundwater depth decreased from 15 m at the inner side of Qira oasis-desert ecotone to around 7 m at the periphery, the crown breadth, total number of branches, newly growing branches in that year and new biomass of *Tamarix ramosissima* increased significantly, while the dead branch ratio decreased.

Tamarix ramosissima with certain crown breadths block sand grains to form nebkhas with the corresponding sizes. The volume of nebkhas increases significantly with crown area, and the crown area is closely related to the total number branches, new branches in that year and new biomass of the shrub.

There is a strong correlation between the length and width of nebkhas, basal area and height, as well as basal area and volume. However, this correlation weakens with increased wind-blown sand activities under single wind direction environment, for the Nebkhas stretching along the prevailing wind direction to form a clear sand tail. The morphological adaptive mechanism of *Tamarix ramosissima* nebkhas can be attributed to the proper groundwater depth which promoted shrubs growth well and affected sand deposition on the shrubs, as well as the interactions and feedback between the shrubs and nebkhas.

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The factors affecting the estimation of pasture biomass using non-destructive methods in the forest-steppe zone of Mongolia

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Abstract

Monitoring of pasture biomass is essential to utilize the resources more efficiently and sustainable way. The standard method to determine the biomass is to cut plants growing in the pasture. But labor and time intensive, and it also causes some damage to the pasture. So, there is a need to develop a non-destructive method which is easy and accurate. Therefore, a field type portable Normalized Difference Vegetation Index (hereinafter referred as NDVI) meter was used in nine different pastures (seven in mountainous and two in meadow pastures) to detrmine NDVI two times in a year at 30 spots which represented the vegetation in each pasture. At the same time, the aboveground parts of the plants in the circles were cut, separated into the live and dead samples, and the dry matter (DM) measured. The amount of chlorophylls was also determined. The results indicated a positive correlation between the amounts of chlorophylls and estimated live biomass of the mountainous pastures, but the high amounts of chlorophylls in the meadow pastures disturbed the estimation of the biomass using the NDVI meter.

Introduction

Monitoring of pasture biomass is essential to utilize the resources more efficiently and sustainable way. The standard method to determine the biomass is to cut plants growing in the pasture. But this method needs much labor and time, and it also causes some damage to the pasture. Therefore, there is a need to develop another method which is easy and accurate and is non-destructive. The spectral reflectance measurement, which estimates biomass derived from Normalized Difference Vegetation Index (NDVI), is a possible method for monitoring pasture condition in a non-destructive way, and is promising one as it is connected with satellite image analysis (Fukuo *et al.* 2008). The NDVI is calculated using the spectral properties of vegetation reflectance in the red (R) and near infrared (NIR) wavelengths (Rouse *et al.* 1974). Green vegetation typically has low reflectance in the R band (630-690 nm) due to radiation absorption by chlorophyll (sing.: Chl, pl.: Chls) pigments, but high reflectance in the NIR band (760-900 nm) due to scattering by leaf mesophyll. As satellites are becoming more popular, the importance is increasing to collect the site specific information by this method and doing the ground truthing using spectral-radiometer (SRM) (Fukuo *et al.* 2008).

The essential role of Chls of plants are various photosynthetic reactions including O_2 evolution, CO_2 fixation, or carbohydrate biosynthesis (Porra 1984). And the efficiency of the reactions is related closely not only to light regimes, but also to nutrients such as nitrogen and other growth relating factors. So, the study on the Chls of the Mongolian pasture plants has its importance from the point of view the nutrient status and the monitoring of the pasture condition (Baasanjalbuu *et* *al*. 2012). A study was, therefore, conducted to find the Chls' status in plants of different types of pastures and the different growing stages in the forest-steppe zone of Mongolia, and determined the correlation between the amounts and the NDVI values.

Materials and methods

Site

The sampling of the pasture plants was conducted at Nart of Bornuur rural district (*sum* in Mongolian), Tuv prefecture (*aimag*), in 2009 and at Oortsog of Argalant rural district, Tuv prefecture in 2011 for two times in a year (June or July and August). The pasture types of Bornuur and Argalant *sum* were classified as the forest-steppe. A total of nine different types of the pastures including seven mountainous steppe pastures and two meadow pastures were chosen based on the first or the first to third dominant plant species and their locations, i.e., *Artemisia frigida* dominant pasture (herein after referred as Artemisia), *Carex duriuscula* dominant pastures located in mountainous pasture and meadow (*Carex* and *Carex*-meadow, respectively), *Cleistogenes squarrosa* dominant pasture (Cleistogenes), *Leymus chinensis* dominant pastures located in mountainous pasture and winter base camp (Leymus and Leymus-winter, respectively), and *Stipa krylovii* dominant pasture (Stipa) at the *Bornuur*, and two types of pastures where multiple plants were dominant, i.e., Grass-herb type mountain steppe pasture and Herb-grass type meadow pastures were chosen at the *Argalant* (Table 1). The 30 spots, which represented the vegetation, were chosen at the each pasture.

Table 1. The studied pastures in *Tuv* prefecture, Mongolia during 2009-2011

Name	Dominant plant species	Location		Biomass (Mean±SE, kg/ha)		
		Place[1)]	GPS[2)]	Time-1[3)]	Time-2	Significance[4)]
Mountanious steppe						
Artemisia	*Artemisia frigida*	1	38°41'49"N; 103°15'20"E	1,084 ±76	1,457 ±41	***
Carex	*Carex duriuscula*	1	46°41'45"N ; 102°15'20"E	625 ±26	1,105 ±27	***
Cleistogenes	*Cleistogenes squarrosa*	1	32°39'09"N; 102°11'20"E	588 ±27	930 ±30	***
Grass-herb	*Stipa Krylovii, Artemisia frigida*	2	47°52'10"N; 106°08'52"E	1,434 ±57	1,575 ±46	*
Leymus	*Leymus chinensis*	1	48°41'16"N; 106°15'18"E	692 ±40	1,349 ±41	***
Leymus-winter[5)]	*the same*	1	48°41'49"N; 106°15'20"E	1,091 ±104	2,164 ±75	***
Stipa	*Stipa Krylovii*	1	47°41'12"N; 101°15'20"E	648 ±29	1,181 ±29	***
Meadow steppe						
Carex-meadow	*the same*	1	40°41'49"N; 100°15'18"E	1,313 ±59	1,357 ±52	ns
Herb-grass	*Artemisia spp., Aconitum barbatum, Thalictrum spp.,Elymus spp.*	2	47°52'10"N; 106°08'52"E	2,474 ±113	3,487 ±159	***

[1)] 1; *Nart* of *Bornuur* rural district (*sum* in Mongolian), 2; *Oortsog* of *Argalant* rural district.

[2)] Data of the Global Positioning System.

[3)] Time-1; Jun., 2009 in the *Bornuur* or Jul. in the *Argalant* 、*Time-2;* August at the *Bornuur* and *Argalant* in the each year.

[4)] ***; p<0.001, **; p<0.01, *; p<0.05, ns; not significant.

[5)] Pasture around winter base camp.

NDVI determination

The field type portable NDVI meter (EBARA Corporation Ltd., Tokyo, Japan), a simplified spectral-radio-meter, was used. It is composed of sensor and controller parts. The measurement was conducted in sunny days for three hours. The person doing the measurement stood at right angle with sun, and set the height and direction of controller to be able to set the end of the sensor exactly at the same height as the plant canopy. Then the reflectance in the R band (650nm) and

NIR band (880nm) was measured in the circles with the diameter of 60.0cm, and the NDVI values were calculated by the following equation (Rouse 1973);

$$NDVI = (NIR - R)/(NIR + R)$$

Sampling and the sample preparation

The upper-ground parts of the plants in the circles were cut, separated in the live and dead samples, put in an oven at 600C degree for more than 24 hours until they were completely dry, and weighed to determine the dry matter (DM).

Assay of chlorophylls

The dried live samples of the each circle were subjected for Chls' assay. The Chls were extracted and the amounts were measured by one of the simplified method recommended by Yamasaki *et al.* (2012a): about 0.01g of the grinded samples were exactly weighed, and put in tubes with 3ml of 90% acetone; the tubes were put for 28hours at room temperature in dark; and the absorbance of the extracts was measured at 663.2 nm or 646.8 nm using absorption spectrophotometer. The concentrations (µg/g sample) of Chl a and b were calculated from the following equations:

$$\text{Chl a } (\mu g/mL) = 12.25\ A_{663.2} - 2.79\ A_{646.8}$$

$$\text{Chl b } (\mu g/mL) = 21.5\ A_{646.8} - 5.1\ A_{663.2}$$

The triplicate samples from the each circle were analyzed and the average data were used for further analysis.

Statistical analysis

The average amounts of Chls were compared by two factorials, pasture types and plants' growing stages using General Linear Model of ANOVA ($p<0.05$). When the interaction between the pasture types and time was found, treatment means were determined. The regression analysis was done between the biomass and the amounts of Chls, and regression equation, coefficient of determination (R^2), and probability (p) were determined by the pasture types. The MINITAB Statistical Software, Release 16, MINITAB Inc. was used for the analysis.

Results and discussion

Differences in the amounts of chlorophylls by pasture types and sampling times

The interactions between the pasture types and sampling time were found for Chl a, b, and a+b ($p<0.001$). The treatment means were determined and they showed almost the same tendencies for Chls a, b, and a+b (Fig. 1).

The amounts of the Chl a+b in the seven mountainous pastures decreased from the Time_1 to Time_2 ($p<0.001$). The decreasing was more than 39.2%, and it was the highest in the Cleistogenes (76.7%). The results are corresponding to the decrease of the nutrients, especially that of nitrogen, as shown by Yamasaki *et al.* (2012b). But the amount in the meadow pastures were nonsignificantly increased from Time-1 to Time-2 ($p>0.05$).

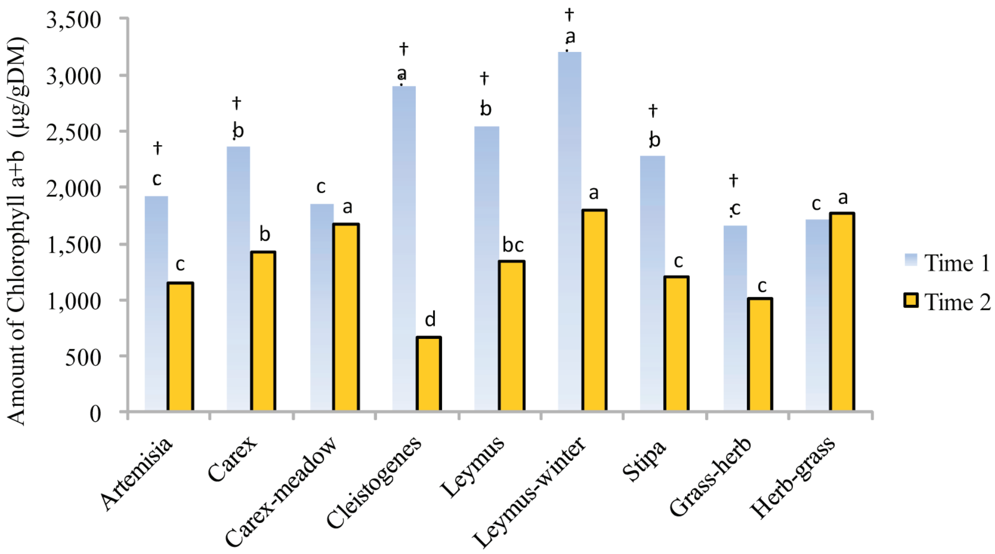


Fig. 1. Treatment means which have a significant interaction by the results of factorial analysis compared between each type of pasture by different sampling time (µg/gDM)

Note: †: Higher than the amount of the other sampling time of the same pasture (P<0.001). a, b, c, d: Significantly different from those of other pastures in the same sampling time (p<0.001).

The amount in the Time-1 was the highest in the Leymus-winter and Cleistogenes (3,190.2 - 2,892.9µg/gDM), second highest in the Carex, Leymus and Stipa (2,533 - 2269.0µg/gDM), and lowest in the Artemisia, Carex-meadow and Herb-grass (1919.0-1,702.0µg/gDM) (p<0.001). But in the Time_2, it was the highest in the Carex-meadow, Leymus-winter and Herb-grass (1,797.0-1,677.0µg/gDM), and the lowest in the Artemisia, Stipa and Grass-herb (1,204.0-1,007.0µg/gDM) (p<0.001).

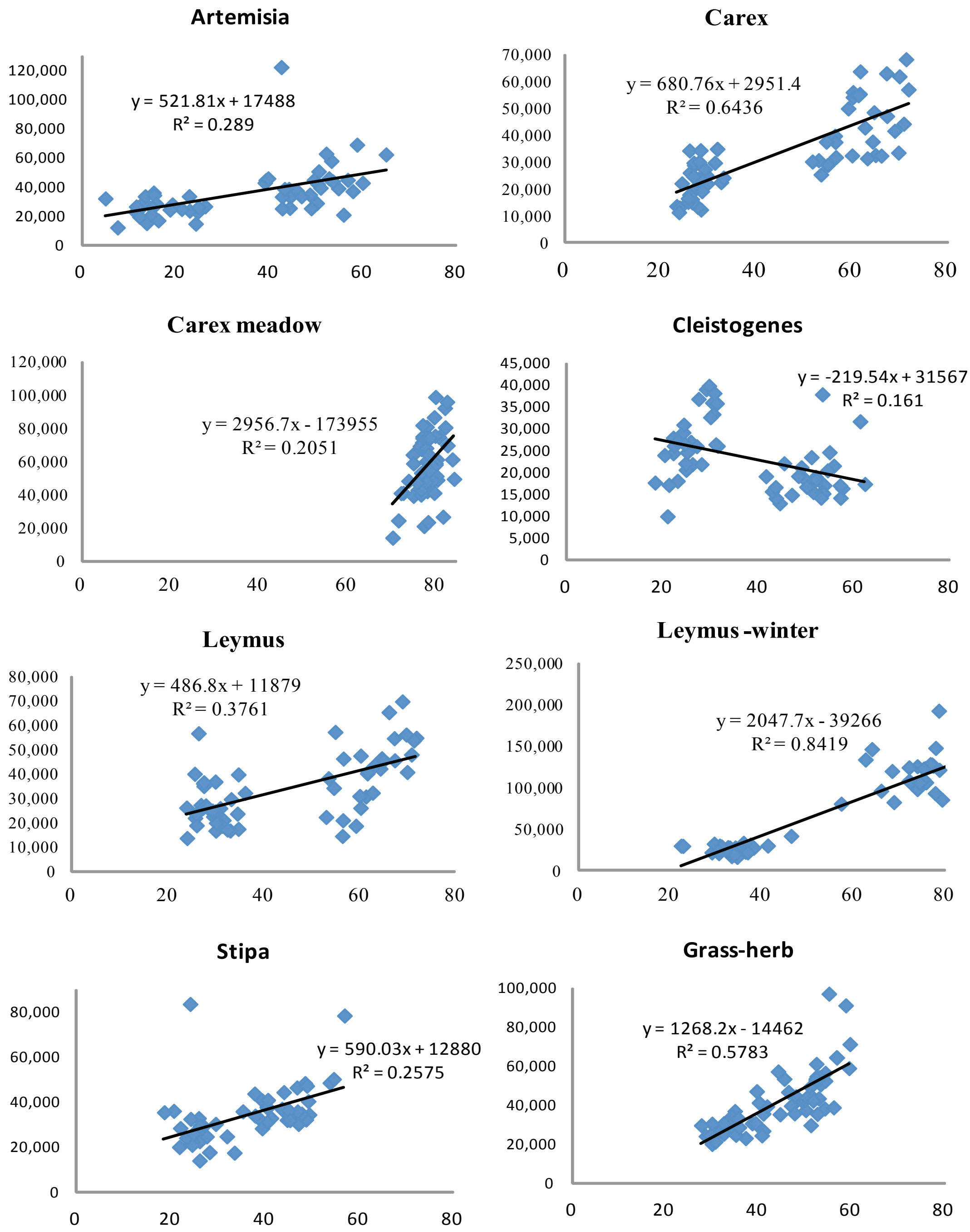
The results would show that the amounts of the Chls were higher in the Time-1 than in the Time-2, and higher in the meadow pastures than in the mountainous pastures in the Time-2. The reason for the high contents of Chls in the Leymus-winter in the Time-2 may be attributed to the deposition of nutrients, especially of nitrogen, as the herders had stayed there and carried their animals.

Regression equation and coefficient of determination

Figure 2 shows scattergram, the regression equation and R2 from the regression analysis between NDVI values vs. pasture LIVE biomass ∗ amount of the Chl a+b. Some of the R2 such as that of the Leymus-winter (0.842) were high, but those of the Leymus (0.161) and the meadow type pastures, Carex-meadow (0.205) and Herb-grass (0.004) seemed to be low. Besides, the NDVI values of the meadow type pastures were around the 0.80, which is the saturation NDVI to estimate the biomass.

Regression equation using Chls amounts for the pastures

All the NDVI values vs. LIVE biomass ∗ amount of Chls were classified into two groups, mountainous pastures and meadow pastures. Then, the regression equations for each group of pasture were developed which are as follows:



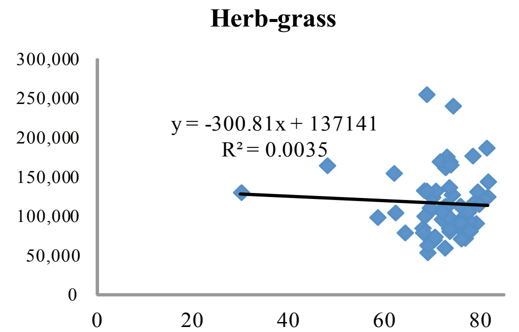


Fig.2. Scattergrams between NDVI values vs. pasture LIVE biomass× amount of the chlorophyll a+b by each of studied pasture

Note: x-axis; NDVI values, y-axis; pasture LIVE biomass× amount of the chlorophyll a+b (μg/0.36m²)

Mountainous pastures: $y = 1001.6x - 3147.7$ ($r=0.65$, $R^2 = 0.4187$, $p<0.001$, $n=413$)

Meadow pastures: $y = -1937.2x + 232190$ ($r=0.086$, $R^2 = 0.0931$, $p<0.001$, $n=117$)

The comparatively high R^2 for the mountainous pastures and low R^2 for the meadow pastures are in agreement with the observations of Baasanjalbuu *et al.* (2012) on the correlation between the NDVI values and biomass.

From the above, it is clear that the content of the Chls reflected the nutrient status of the pasture plants. And it was also indicated that there was a positive correlation between the amounts of chlorophylls and the estimated live biomass of the mountainous pastures, but the high concentration of Chls in the meadow type pasture plants in autumn disturbed the estimation of pasture biomass using NDVI meter.

Conclusion

A positive correlation was found between the amount of chlorophylls and the estimated live biomass of the mountainous pastures, but the high proportion of Chls in the meadow type pasture plants in autumn disturbed the estimation of the pasture biomass using NDVI meter.

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Preparation and utilization of supplemental feeds during cold seasons at herders' household in Mongolia

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Abstract

A study was conducted to clarify actual condition of supplemental feeding at herders' households in forest-steppe and steppe areas. The Tuv prefecture (hereinafter referred as T_pref.) located in the forest-steppe and Uvrhangai prefecture (hereinafter referred as U_pref.) located in the steppe were chosen as study sites. A total of 163 herders' households were visited with a questioner during September and October, 2010 and asked about the conditions in the last cold seasons. Followings were some of the main questions: 1) types and numbers of animals carried, 2) whether the feeds were prepared/supplied, and the types of animals which received the feeds, 3) types and amounts of the feeds prepared, and 4) plan on preparation and utilization of the feeds in future. The data of the households which carried cattle more than 50% of total number of animals were excluded. The results indicated that: 1) most of the studied households carried sheep, goats, horses and cattle, and total numbers of the animals per household calculated by livestock unit in Mongolia were more in T_pref. (607 heads) than in U_pref. (442 heads) ($p<0.05$); 2) most of the households supplied the feeds to the 4 types of animals; 3) hay and wheat bran were used in more than 80% households; and 4) more than 60% households intended to increase the amounts of hay and wheat bran, and were expected to prepare silage using brewers' grain and commercial mixed feed in T and U_pref., The overall results emphasize the importance of establishing the feeding management system considering the differences in the situations of the area.

Introduction

The pastoral livestock production system in Mongolia has traditionally been carried on in natural open pastures with five species of animals: sheep, goats, cattle, horses and camels, and it has played a crucial role in the domestic economy. But the productivity of the system is extremely seasonal, with animals losing 20-30% of their live weight in spring from their peak weight in autumn, because pastures lay dormant from the previous year due to cold or snow (FAO 1990; Purev 1990). And the availability of hay, cultivated fodder and other feeds is a key constraint in livestock production.

Recent socio-economic reforms included the introduction of a market economy and enactment of the Private Ownership Act, which went into effect in the late 1980s and was accelerated in the early 1990s. This exerted a large influence on the pastoral livestock production system. However, the constraints have continued until now. Not only the livestock population, but also the number of herdsmen had continued to increase in the 1990s because of a high rate of unemployment throughout the country and insufficient wages for those who were employed (Cooper 1995; Enkhamgalan 1995; Muller 1995; Gelder 1999). Excessive grazing in natural pastures, accelerated during the 1990s especially in and around centers, was alarming as herdsmen and livestock were more densely concentrated there than in other areas (Enkhamgalan 1995; Muller 1995). In addition, fodder production in the fertile forest steppe decreased sharply; the price of fodder rose dramatically (Cullis *et al.* 1993; Jigjidsuren 1993; Enkhamgalan 1995; Suttie 2000) and herdsmen were restricted more strictly to natural pastures around their quarters during the cold.

These situations might demonstrate the decreasing sustainability of the production system, and the increasing risk of cold and snow disaster (*Dzud* in Mongolian). Some reports have therefore stressed the necessity of preparing more fodder for harsh seasons to avoid the starvation of animals (Cullis *et al.* 1993; Jigjidsuren 1993; Yamasaki & Ishida 2004). As the Dzud occurred twice during the last decade, 1999-2002 and 2010, and huge numbers of animals were lost (National Statistical Office of Mongolia 2012), it means that the constraints in 2000s were similar to those in 1990s.

The Mongolian government is now identifying effective ways to reduce the risk of Dzud and bring improvements to the animal husbandry sector. The parliament approved in 2010 the "Mongolian National Livestock Program", which settled relevant issues and contained a comprehensive plan for the next 10 years, and now seeking the ways to perform the program in practice. Therefore, a field study was conducted to describe the actual condition on the supplemental feeding at herders' households and to find the problems and constraints, which were needed to be solved, to establish the sustainable livestock production system.

Materials and methods

Studied areas and households

Mongolia (area 1,564,100km2) is divided into several areas, according to its ecological characteristics, and the main areas for animal husbandry are in central to north-western highland of forest steppe, vast eastern prairie of steppe, and southern lowland of desert. Tuv prefecture (hereinafter referred as T-pref., area 74,000km2) surrounds Ulaanbaatar city (area; 4,700km^2), capital of the country, and Uvrhangai prefecture (U-pref., area 62,900km2) is located south-west form the T pre. A study was conducted at the two rural districts (soum in Mongolian) of the each prefecture, i.e., T1 and 2 in T-pref. and U1 and U2 in U pref. The general information is summarized in Table 1.

Field study

Field study was conducted duringt September and October, 2011, and a total of 163 herders' households (40 households in the each of the T1, U1 and U2, and the 43 households in the T2) were chosen and visited with a questioner during September and October, 2010. They were asked about the conditions in the last cold seasons.

Following were some of the main questions: 1) types and numbers of animals carried, 2) whether the feeds were prepared/supplied, and the types of animals which received the feeds, 3) types and amounts of the feeds prepared, and 4) plan on preparation and utilization of the feeds in future. The data of the households which manage dairy mainly, i.e., the households which carried cattle more than 50% of total number of animals, were excluded. Then, the data of the 21 and 64 household in T and U pref., respectively, were used for the analysis.

Table 1. Vegetation type, area and animal production at the studied areas in 2011

	Tuv prefecture				Uvrhangai prefecture			
	T1[1)]		T2		U1		U2	
Vegetation type	FS[2)]		FS		S		FS/S	
Area (km^2)	2,431		613		1,760		2,241	
No. of herder's household	735		796		831		1300	
No. of animals (% of total)[3)]								
Sheep	23,868	(12.6)	16,142	(19.1)	57,586	(34.6)	79,155	(28.4)
Goats	18,680	(9.9)	12,571	(14.9)	30,681	(18.5)	56,301	(20.2)
Cattle	102,750	(54.3)	34,992	(41.4)	19,608	(11.8)	47,244	(17.0)
Horses	43,799	(23.1)	20,797	(24.6)	57,358	(34.5)	94,080	(33.9)
Camels	120	(0.1)	0	(0.0)	966	(0.6)	1,518	(0.5)
Total	189,217	(100.0)	84,502	(100.0)	166,199	(100.0)	278,298	(100.0)

1) T1; Batsumber *soum* (rural district), T2; Baynnchandmani *soum* , U1; Uljit *soum* , U2; Harhorin *soum* .

2) FS: *forest-steppe* , S: steppe.

2) Calculated by Mongolian livestock unit (sheep: goats: cattle: horses: camel = 1: 0.9: 6: 7: 6.

Statistical analysis

Results regarding the frequency were converted into and treated as numerical numbers. Then, all of the numerical numbers were analyzed by General Linear Model of two factorial ANOVA using Minitab Statistical Software Version 16 (Minitab Co. Ltd.) to find out the differences by the areas and their interaction (Ryan *et al.* 2000). Where interactions were significant, the differences between the means were compared by the Tukey test at the 5% level of probability.

Results

Types and numbers of animals

More than 96% of the studied households in the both prefectures carried each of sheep, goats, horses and cattle, and only the 2.4% carried camels. No significant difference was found ($p>0.05$) between the prefectures in the type of the animals carried. No interaction was found between the animal types and areas ($p>0.05$). A significantly greater number of sheep (204 heads/household) and lower number of camels (2.3 heads/household) compared with those of other animals were herded ($p<0.001$), and the total number of animals per household was more in T-pref. (606.7 heads) than in U-pref. (440.0 heads) ($p<0.01$).

Actual condition of preparation and unitization of supplemental feeds

The most (96.1%) of the studied households prepared supplemental feeds, and more than 75% households fed the feeds to the each of the four types of animals, or besides camels. Significant interactions were found, on both of the proportion of households and the amounts of the feeds, between the different feed types and the areas ($p<0.001$).

In T-pref., the proportions of households which prepared each of the supplemental feed were significantly highest in hay (100%), minerals and wheat bran (90.5% for the both), and next highest in fodder crops (33.3%) ($p<0.001$). There were no household which prepared mixed feed, barley residue, and brewers' and distillers' grains. Hay (93.8%) and wheat bran (82.8%) were prepared significantly more frequently ($p<0.001$) than other feeds in U-pref. as also in T-pref. But the proportions in U-pref. were significantly higher ($p<0.01$) in mixed feed (28.1%, $p<0.01$) and lower ($p<0.001$) in minerals (10.9%) and wheat residue (0.0%) than in T-pref.

Demands for supplemental feeds

All of the studied households in the T-pref. intended to increase the amount of the feeds in future, though 15.6% households in U-pref. intended to reduce or not to increase.

In T-pref., 85.7% households intended to increase the amounts of hay and wheat straw, and 65.0-76.2% households intended to increase for minerals, wheat bran and brewers' grain. Only 4.8-9.5% households intended to increase the home/hand-made feeds and distillers' grain. On the other hand, the proportion of hay (79.7%) and wheat bran (68.3%) were significantly higher ($p<0.01$) or tended to be higher ($p<0.1$), respectively, than those of other feeds in U-pref. The proportions on minerals, home/hand-made feeds, and brewers' and distillers' grain (10.9-15.6%) were significantly lower than those on other feeds ($p<0.01$). The proportions of the households which intended to increase the amount of wheat straw, minerals and wheat residue were higher in T-pref. than in U-pref. ($p<0.001$).

The reasons given for the increase in the amount of supplemental feeds were to increase the number of animals (57.1 and 53.1% in the studied households in the T and U_pref., respectively, to improve the productivity of the animals/animal products (71.4 and 64.1%), and to guard themselves against the natural disasters (85.7 and 60.9%). The proportion which mentioned "the disasters" as the reason were higher in T-pref. than in U_pref. ($p<0.05$). In addition, the household which mentioned to prevent pasture degradation or to conserve the pastures were more in T-pref. (66.7%) than in U-pref. (10.9%) ($p<0.001$).

Techniques expected to be improved

Some 66.7-76.2% of households in T-pref. expected the improvement of techniques of silage preparation using brewers' and distillers' grains, pasture plants and vegetable by-products/wastes. The pasture plants (79.7%) and vegetable by-products/wastes (71.9%) were expected in U-pref., too, but the grains (14.1%) were less ($p<0.001$) expected than the other materials than in T-pref. ($p<0.001$).

Discussion

The Mongolian herders usually carry the four or five types of animals, and use the animal products based on the differences in their quality and quantities. The herd compositions differ by locations and ecological zones, e.g., more animals are tended to be carried in the remote areas compared with the areas in/around the population centers such as the capital city; and more cattle are carried in/around the centers than in the remote areas; and camels are mainly carried in the southern semi-desert or desert area. Therefore, the results would reflect the differences in the actual conditions of the animal production based on the differences in the areas. Data of about half number of households in the T-pref. were excluded as they carried cattle more than the total number of their animals calculated by MLU; and most of the studied household carried four types of animals except camels.

The most of the studied households, as seen in the results, used the feeds for their animals during the harsh seasons. And the easiness of access to the feeds, including the costs, would have affected the results on the types and the amounts of the feeds used at the households. Hay and wheat bran were the typical supplemental feeds for Mongolian herders, as they could harvest and/or prepare the hay by themselves, and wheat was domestically cultivated and the bran was sold in the almost whole areas in the country (Yamasaki & Ishida 2004). So, these were most popularly used in the both prefectures. Minerals, usually called as Hojir in Mongolian and contain mainly sodium chloride, were produced in southern regions in the country including desert and desert-steppe, and transported to northern regions. So, the necessity for the minerals was higher in T-pref. than in U-pref. Brewers' grain was produced only at factories in big city, or in Ulaanbaatar. Its price on dry weight basis was lower compared with other feed materials. But its high content of water and high cost for transportation forces herders to use these only in/around the city. Wheat and fodder crops were mainly cultivated in the fertile forest-steppe regions including the T-pref.. Being from the wheat farm and brewers' factory, the demand for commercial mixed feed was higher in U-pref. than in T-pref.

The ease of access to the feeds was the main factor for the expectation to increase the amount of the feeds, too. For example, wheat straw was expected at the higher proportion of the studied households in T-pref. than in U-pref. as most of the cultivated land for wheat was distributed in the northern area of the country including the T-pref.

As for the reasons for the expectation to increase the feeds, the first two reasons (to increase the number of animals and to improve the productivity of animals/animal products) are directly related to the desire of herders to increase their income and improve the living standard. On the other hand, the next two reasons (to guard against the natural disasters and to conserve the pasture), are more proactive, and the proportions of herders which mentioned these reasons were higher in the T-pref. than in the U-pref. The results indicate that many herders had been gathering in/around the population centre from remote areas, and the herders tended to be anxious about the pasture degradation and more interested in ensuring that they are not affected by natural disasters.

With respect to the techniques expected to be improved, it was found that the herders were interested in increasing the amount of supplemental feeds and improving the preparation techniques, and they considered the use of the locally available resources which were relatively easy to access in their areas.

Conclusion

The overall results emphasize the importance to establish the feeding management system considering the differences in the situations of the area.

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Difference in the rate of fermentation of brewers' grain silage caused by mixing rations of wheat bran or wheat screenings in Mongolia

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Abstract

Brewer's grain (BG) is one of the most important feed resources, especially as a source of protein. But its usage in Mongolia is restricted during the summer because of its high moisture content, or ease of decay, and high cost of transportation. So there is a need to develop an improved method to store and conserve its nutritional values until the following spring when the demand for BG increases. A study was, therefore, undertaken to determine differences in the fermentation quality of brewers' grain silage based on the use of different types and amounts of additives for different periods. Five treatments were studied: 100%BG (BG100 for short. 82.0% moisture), 90%BG: 10% wheat bran (WB, WB10, 74.2% moisture), 80%BG: 20%WB (WB20, 66.2% moisture), 90%BG: 10% wheat screenings (WS, WS10, 73.5% moisture) and 80%BG: 20%WS (WS20, 65.6% moisture). The pH, proportions of lactic acid and volatile fatty acids, including acetic (C2), propionic (C3), butyric (C4), valeric (C5) and caproic (C6) acids, were determined at 0, 3, 7, 14, 21 and 28 days (d). Fermentation quality of WB20 was the best and fastest as the pH decreased to below 4.2, the proportion of lactic acid increased to more than 1.5% at 3d, and proportion of C2+C3 and C4 acids did not increase by more than 0.2 and 0.1%, respectively, until 28d. The next best treatment was WB10, as the quality was almost the same as that of WB20, though the proportion of lactic acid reached 1.5% at 28d. The third best treatment was WS20, as the proportion of lactic acid neared the recommended level at 28d. But, based on the cost of different methods, WB10 was recommended for herders as it was relatively less expensive.

Introduction

The pastoral livestock production system in Mongolia has traditionally been carried on in natural open pastures and has played a crucial role in the domestic economy. The productivity of the system is extremely seasonal, with animals losing 20–30% of their live weight by spring compared with their peak weight in autumn as a result of cold temperatures and snow cover (Enkhamgalan 1995; Purev 1990), and low nutritional values such as crude protein and total digestible nutrients in pasture plants remaining dormant from the previous year (Yamasaki *et al.* 2013). In addition, since the introduction of a market economy in the early 1990s, the number of livestock has increased (National Statistical Office of Mongolia 1999), and a winter-spring disaster occurred twice, in 1999 and again in 2010, resulting in the loss of huge number of animals (United Nations 2010). Establishment of a sustainable livestock production system, under these circumstances will necessitate improvement in supplemental feeding throughout the country (Yamasaki and Ishida 2004).

Brewers' grain (BG), the material that remains after grains have been fermented during the beer making process, is one of the most important feed resources as it is rich in energy, protein, fiber and fat content (MAFF 1995). Its production has been increasing year by year (National Statistical Office of Mongolia 2012), but its usage in the country is restricted during the summer because of its high moisture content, or ease of decay, and high cost of transportation. To store and conserve its nutritional value, the wet BG is either ensiled or it is dried in the same manner as distiller's dried grains with solubles (DDGS). Both dry BG and DDGS are easy to handle and transport, but investment in a large plant is required for drying. On the other hand, ensiling is possible for even small-to-medium sized farmers and/or herders. But the nutritional content of the material varies from plant to plant and depends on the type of grain used in the initial brewing process (barley, wheat, corn, etc.) as well as on the proportions being fermented and the fermentative process being used. In addition, an adequate method to prepare the silage has not yet been determined in the country.

Therefore, a study was undertaken, using materials which were easily obtained in the country, to determine differences in the fermentation quality of BG silage with the use of different types and amounts of additives as a dryer for different periods.

Materials and methods

Materials and silage preparation

Fresh brewers' grain (BG) purchased on the day of preparation from the brewers' company located in Ulaanbaatar city was used. Wheat bran (WB) and wheat screenings (WS) were chosen as additives because they are commonly used as supplemental feeds by herders and are suitable as additives as they have low moisture content. The additives were purchased beforehand from a company in the city.

A total of five types of silage were prepared based on the weight of fresh matter (FM): 100%BG (BG100 for short, 82.0% moisture), 90%BG: 10% WB (WB10, 74.2% moisture), 80%BG: 20%WB (WB20, 66.2% moisture), 90%BG: 10% WS (WS10, 73.5% moisture) and 80%BG: 20%WS (WS20, 65.6% moisture) (Table 1).

Table 1: Mixed ratio of brewers' grain and wheat bran or wheat screenings

	Mixed Ratio, %FM[1)]			Moisture, %FM
	Brewers' grain	Wheat bran	Wheat screenings	
BG100[2)]	100			82.0
WB10	90	10		74.2
WB20	80	20		66.2
WS10	90		10	73.5
WS20	80		20	65.6

[1)]FM; fresh matter; [2)] BG100; used only brewers' grain (BG), WB10; mixed with 90% BG and 10% wheat bran (WB), WB20; mixed with 80% BG and 20% WB, WS10; mixed with 90% BG and 10% wheat screenings (WS) and WS20; mixed with 80% BG and 20% WS.

The preparation was done in only two days in the summer season; the BG100, WB10 and WB20 were prepared on June 30, 2010, and the WS10 and WS20 were made the next day. Fresh BG was directly used for the BG100, and the wheat bran or wheat screenings were mixed well with the BG in WB10, WB20, WS10 and WS20 before packing. Four 30L plastic containers with plastic bags inside were used for the preparation. To establish the anaerobic environment as quickly as possible and to promote lactic acid fermentation, the mixed materials were put in plastic bags up to the top of the bottle, the air in the materials and bags was aspirated by sweeper, the bags were tied with strings, and the caps were sealed using silicon until the day of the sampling. The samples were collected at 0, 3, 7, 14, 21 and 28th days (d) after preparation. There were four replications of each treatment and the sampling day.

Determination of fermentation quality

The samples were treated on the day of collection for measurement and analysis. The fresh samples, approximately 60-70g, were blended with 140mL distilled water, shaken and put in refrigerator for 24h at 4 °C for extraction. Then the liquid was filtrated through four layers of gauze put on filter paper. Soon after the filtration, the filtrates were measured with regard to pH using a glass electrode pH meter, and then frozen. The frozen filtrates were defrosted, and the contents of the organic acids, i.e., lactic acid and volatile fatty acids (VFA), including acetic (C2), propionic (C3), butyric (C4), valeric (C5) and caproic (C6) acids, were measured by high-powered liquid chromatography(HPLC) (Hosoda *et al.* 2006).

For evaluation of the fermentation quality of each of the pH and organic acids, ranges recommended by Cai (2009) were used. Also, the content of C2 plus C3 was assumed to be that of C2, and VFA equal to or higher than C4 were combined and assumed to be C4. The data on the last day of the experiment were evaluated using Flieg's scores (Japan Livestock Technology Association 2000).

Economic and nutritional evaluation

The 1.3t wet brewers grains and 25kg wheat bran were purchased with 7,800 Mongolian Tugrug (MNT; USD1.0 was equivalent to MNT1360) and MNT 5060, respectively. The price of the wheat screenings was nearly equal to that of the WB. The transport cost of BG was MNT50, 000. The chemical composition of the feed materials was as follows: (1) wheat bran: dry matter (DM) 12.5%; crude protein (CP) 19.0%; total digestible nutrition (TDN) 69.5%, (2) wheat screenings: DM; 11.3%; CP 15.2%; TDN 75.6%, and (3) brewers grain: DM 12.0%; CP 24.7%; TDN 67.8%. Using the above values, the feed cost and chemical composition of WB, WS and the silage were estimated.

Statistical analysis

The average values of the Flieg's evaluation scores by the types of silages at 28d were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Miinitab Software version 16.2.1 (Minilab 2010). When the F-test was significant ($P<0.05$), Tukey's pairwise test was used to compare means.

Results and discussion

Table 2 shows the durations to reach the recommended/non-recommended ranges of pH and the content of the organic acids in the prepared silage.

Table 2: Durations to reach the recommended/non-recommended ranges of pH and the contents of lactic acid and volatile fatty acids in the prepared silage[1)]

	pH		**Contents, %FM[2)]**		
			lactic acid	**C2+C3**	**C4**
	4.3-4.5[3)]	-4.2	1.5-2.5	0.2-	0.1-
BG100[4)]	21[5)]	no[6)]	no	21	exp.[7)]
WB10	3	3	28	no	no
WB20	3	3	3	no	no
WS10	3	3	exp.	28	no
WS20	3	3	exp.	no	no

[1)]The volatile fatty acids include acetic (C2), propionic (C3), and butyric and iso-butyric (C4) acids. Valeric, iso-valeric acids (C5), and caproic and iso-caproic acids (C6) were also determined but were not detected; [2)]See Table 1; [3)]Relating to pH, less than 4.2 is classified as "good"; 4.3-4.5 is "medium" and over 4.5 is "bad". Relating to lactic acid, C2+C3 and C4, 1.5-2.5 is "good", over 0.2 is "bad" and over 0.1 is "bad", respectively; [4)]See Table 1; [5)]Numbers show the duration, or the days, to reach into the each range; [6)]Did not reach each range during the experimental period, and were not expected to reach; [7)]Didn't reach each range during the experiment period, but expected to reach soon.

The values of the pH started from 5.2-5.3 at 0d in all of the samples. The values decreased gradually to reach 4.2 at 28d in the BG100 silage, but they decreased quickly to the same level from 3d in the other silage. The proportions of lactic acid in the fresh samples at 0d were around 0.10%. The amount in BG100 did not increase during the experiment. On the other hand, the amounts increased to 1.52% in WB10 at 28d, 1.53% in WB20 at 3d. The proportions in WS10 and WS20 also increased linearly; 1.16% in WS10 and 1.24% in WS20. In the VFA, the C5 and C6 were not detected. The amounts of C2+C3 increased more or less from 0.03 to 0.04%FM in all of the silage. The amount reached 0.33%FM in BG100 at 21d, and 0.29%FM in WS10 at 21d. But those amounts in the other silage were equal to or less than 0.12%FM until 28d. The amount of the C4 increased linearly only in BG100 to 0.25%FM at 14d and 0.63% at 28d, and the amounts did not increase or were not detected in the other silage until 28d.

The results of the evaluation of silage fermentation qualities using Flieg's scores at the end of the experiment are shown in Table 3. The scores of WB10, WB20 and WS20 were full for all of the lactic acid, C2+C3 and C4; the total scores added up to 100.0. In the case of WS10, the score of the C2+C3 was 17.8, and the total score was 97.8, but there was no significant difference between both the C2+C3 and the total scores of other silage using WB or WS ($p>0.05$). As for the BG100 silage, the pH decreased slowly; the amount of lactic acid did not increase; and the amounts of the VFA increased until 28d. Therefore, Frieg's score was also law, and it is possible to say the fermentation quality of the BG100 silage was not good.

To utilize the silage as part of the herders' feeding management, banker, stack or trench type of silos would be necessary because a large amount of feed would need to be prepared. These types of silos are usually more difficult to keep in anaerobic condition, so there is a possibility that the fermentation quality under practical conditions would be lower than the quality obtained in this experiment. Thus, we are not able to recommend the preparation of BG100 silage.

Table 3: Evaluation of silage fermentation qualities using Flieg's scores at the end of the experiment.

	Scores			
	lactic acid	**C2+C3[1)]**	**C4**	**total**
BG100[2)]	0.0	12.0 a[3)]	-10.0	2.0 a
WB10	30.0	20.0 b	50.0	100.0 b
WB20	30.0	20.0 b	50.0	100.0 b
WS10	30.0	17.8 b	50.0	97.8 b
WS20	30.0	20.0 b	50.0	100.0 b
SEM[4)]	0.00	0.69	0.00	0.69
p[5)]	-	***	-	***

[1)] See Table 2-1); [2)] See Table 1; [3)] Significantly different between the different superscripts; [4)] SEM; Standard error mean; [5)]***; p<0.001;

As far as the Flieg's scores, the fermentation qualities of silage using WB or WS were superior, though the amount of C2+C3 increased slightly until 28d in the WS10 silage. On the other hand, the tendencies were that the duration to reach the recommended range in lactic acid was the shortest in WB20 (3d), the next in WB10 (28d) and was expected to be followed by WS10 and WS20. These results show as follows; for fermentation quality, it was better to choose WB than WS as an additive; and the amount of water-soluble carbohydrates would be more in the liquid of the silage with WB or ground material than in the WS or non-ground material with husk. In addition, the quality was better in the silage mixed with 20% WB or WS than with 10% of the same additives; this would be because of the decrease of moisture content. Thus, it is possible to recommend, in the framework of the fermentation qualities, mixing WB, rather than WS, and at 20%, rather than 10%.

Table 4 shows the results of the estimation of feed costs and chemical composition of WB, WS and silage. The feed costs for 100kgDM were MNT23,131 for WB and MNT3,333 for BG100. Subtraction of the cost of the WB100 from that of WB, approximately MNT20,000/100kgDM, would be the cost to process the wet BG to dry BG or DDGS. The feed costs for the silage were cheaper than those of the WB and WS in both forms, FM and DM.

The magnitude of the differences among WB, WS and the silage were not great with regard to the chemical composition of both CP and TDN on a DM basis. But on FM basis, the proportions of the CP and the TDN were around one third of those of the WB. The FM basis was, in other words, as fed basis. So, it is necessary to prepare and transport three times the amount of silage if we want to serve nearly the same amounts of CP and TDN as those with WB.

Assuming that the 2tFM feeds are transported 15km from the plant or shop, the total of the feed cost plus transportation is nearly equal to between 2tFM WB and 6tFM WB10 transported to 40km distance. It may be possible to increase the distance to 60km or longer when the cost of

Table 4: Estimation of feed costs and chemical composition of wheat bran, wheat screenings and silage

	Feed cost, MNT[1]				Chemical composition[2, 3]							
					CP				TDN			
	/2tFM[4]		/100kgDM		%FM		%DM		%FM		%DM	
WB[5]	404,800	(789)	23,131	(233)	16.6	(294)	19.0	(86)	60.8	(356)	69.5	(105)
WS	404,800	(789)	22,818	(230)	13.5	(238)	15.2	(69)	67.1	(393)	75.6	(114)
BG100	12,000	(23)	3,333	(34)	4.4	(78)	24.7	(112)	12.2	(72)	67.8	(103)
WB10	51,280	(100)	9,938	(100)	5.7	(100)	22.0	(100)	17.1	(100)	66.2	(100)
WB20	90,560	(177)	13,396	(135)	6.9	(122)	20.4	(93)	21.9	(128)	64.9	(98)
WS10	51,280	(100)	9,675	(97)	5.3	(94)	20.2	(92)	17.7	(104)	66.8	(101)
WS20	90,560	(177)	13,163	(132)	6.3	(110)	18.2	(83)	23.2	(136)	67.4	(102)

[1] The 1.3t wet brewers' grains and 25kg wheat bran (WB) were purchased with 7,800 Mongolian Tugrug (MNT, USD1.0 was equivalent to MNT1,360. on June 30, 2010) and MNT5,060, respectively, in June, 2010, and the price of the wheat screenings was nearly equal to that of the WB; [2] CP; crude protein, TDN; total digestible nutrition; [3] The internal data of the authors are used for the estimation, i.e., wheat bran: moisture 12.5%; CP 19.0%; TDN 69.5%, wheat screenings: DM; 11.3%; CP 15.2%; TDN 75.6%, BG: DM 12.0%; CP 24.7%DM; TDN 67.8%; [4] FM; fresh matter, DM; dry matter; [5] See Table 1-2).

transportation is more strictly estimated, and the technology to reduce the proportion of moisture of the wet BG is improved.

Actually, there are many dairy farms 30-70km from Ulaanbaatar city. Therefore, it may be possible to supply the silage to the farms there. But in the case of WB20 silage, there seems to be no value in its use due to feed plus transportation costs compared with those of WB, and it may be possible to use WB20 only in close proximity to the plant producing it. Therefore, based on the cost performance of different methods, the WB10 method is recommended for herders as it is relatively less expensive. Besides the cost performance, the water contained in the silage maybe very advantageous to livestock producers in areas where water quality and supply are limited.

Conclusions

The fermentation quality of WB20 was the best; the next best was WB10. But, based on the cost performance of the different methods, the WB10 method was recommended for herders as it was relatively less expensive.

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Theme 7
Application of new technologies for the improvement of stress (drought, heat, cold and salinity) resistance of crops and conventional and breeding for dry areas

Evaluation of Kabuli type chickpea under stress and non-stress conditions of Iran

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Abstract

Drought stress is one of the most important abiotic stresses in the world reducing grain yield of crops. Nearly 98% of chickpea area in Iran is planted in rainfed condition. In order to study the response of different chickpea genotypes to drought stress and to identify drought tolerant and high yielding genotypes, this experiment was conducted with 40 kabuli chickpea lines along-with susceptible check (ILC 3279). The experiment was performed in a RCB design with two replications under stress (rained) and non-stress drought (irrigated) conditions in three research stations (Kermanshah, Maragheh and Shirvan) in Iran during 2006-07 and 2008-09 cropping seasons. In order to evaluate of chickpea genotypes for drought stress, stress susceptibility index (SSI), stress tolerance index (STI), geometric mean productivity (GMP), tolerance index (TOL), mean productivity (MP) and harmonic mean values (HARM) were calculated. 'FLIP 02-70C', 'FLIP 02-48C' and 'FLIP 02-69C' had high indices for GMP, STI, MP and HARM and were identified as drought resistant genotypes. The phenotypic correlation of MP, GMP, STI and HARM with seed yield in both stress and non-stress conditions were significant. These are recommended as desirable indices for identifying resistant chickpea genotypes.

Introduction

In Semi- Arid Tropics (SAT) and in West Asia and North Africa (WANA), especially in Iran that is considered as dry and semi dry country, the major abiotic constraint for crop production is drought. Often drought is accompanied by relatively high temperatures, which promote evaportranspiration and hence could accentuate the effects of drought and further reduce crop yields. Some 50% of the total crop area is planted in rainfed conditions in Iran due to water limitation. Productivity of crops in rainfed area is 42 percent of irrigated field.

Chickpea (*Cicer arietinum* L.) is grown on 508,000 hectares in Iran, which ranks third after India and Pakistan in the world (Anonymous 2011). Chickpea is the most important legume of the country and is grown on more than 64% of the total food legume area. Major chickpea area (98%) is planted in rainfed condition in rotation with cereals, mainly wheat and barely. The long term average of annual rainfall in Iran is 252mm . It reduced to 127.3 mm in 2007-2008, which was a sever dry season (Islamic Republic of Iran Meteorological Organization 2010). Most of the farmers grow this crop in marginal areas in the spring. Due to lack of rainfall during flowering, podding and seed filling, terminal drought stress is major abiotic stress for reducing chickpea productivity in Iran. Therefore, selection for early maturity chickpea line is the most important objective for escaping terminal drought stress.

Toker and Cagirgan (1998) reported seed yield of chickpea(*Cicer arietinum* L.) lines when grown under non-stress condition increased by 53% as compared to stress condition. Estimates of yield losses due to terminal drought range from 35 to 50% across the SAT and WANA (Sabaghpour 2006). Rahangdale *et al*. (1994) reported that water stress decreased seed yield 15.2%. Yield reduction ranged from 30 to 60 %, depending on geographical region and length of crop season. Chickpea is more sensitive to water stress during its reproductive growth and consequently experiences substantial yield loss (Nayyar *et al*. 2005).

Plants adapt to drought environments either through escape, avoidance, or tolerance mechanisms (Sabaghpour 2006). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Ys) and non-stress (Yp) environments and mean productivity (MP) as the average yield of Ys and Yp. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992) defined a new advance index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Other yield based estimates of drought resistance are geometric mean (GM), mean productivity (MP) and TOL. The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (Ramirez and Kelly 1998).

The present study was conducted to evaluate the ability of several selection indices to identify drought tolerance in chickpea genotypes.

Materials and methods

The experiment was conducted with 40 Kabuli type chickpea lines along with a susceptible check ('ILC 3279'). These were sent by the International Center for Agricultural Research in the Dry Areas (ICARDA) as CIDTN. The experiment was performed in a RCB design with two replications each under rain-fed (non-irrigated) and irrigated conditions at three research stations (Kermanshah, Maragheh and Shirvan) in Iran during the 2006-07 and 2008-09 cropping seasons. The genotypes were planted as single row, 30 cm apart, with 10 cm plant spacing within a row. Fertilizers were applied prior to ploughing at the recommended rates of 20 kg/ha N and 30 kg/ha P_2O_5. Appropriate pesticides were used to control pest.

In order to evaluate the response of different chickpea genotypes to drought stress and identify tolerant genotypes, six selection indices, viz., stress susceptibility index (SSI), stress tolerance index (STI), geometric mean productivity (GMP), tolerance index (TOL), mean productivity (MP), and harmonic mean (HARM), were calculated based on grain yield under drought-stressed and irrigated conditions as follows:-Stress Susceptibility Index (SSI) = (1-(Ysi/Ypi)/SI; Stress Tolerance Index (STI) = (Ypi×Ysi)/Yp^2,Tolerance Index (TOL) = Ypi-Ysi, Geomertric Mean Productivity (GMP) =√Ypi × Ysi, Mean productivity (MP) = (Ypi+Ysi)/2, and Harmonic Mean (HARM) = 2(Ys X Yp)/ (Ys+Yp).

Table 1: Resistance indices of 40 chickpea genotypes under stress and non-stress environments at two locations in two cropping seasons

ENT	Genotype	Yp	Ys	SSI	STI	TOL	MP	GMP	HARM
1	FLIP 87-59C	1656	1031	1.04	0.93	626	1343	1306	1270
2	FLIP 92-113C	1473	876	1.11	0.70	597	1175	1136	1099
3	FLIP 96-154C	1403	904	0.98	0.69	499	1154	1126	1100
4	FLIP 98-79C	1008	678	0.90	0.37	331	843	826	810
5	FLIP 00-14C	1353	845	1.03	0.62	508	1099	1069	1040
6	FLIP 01-4C	1298	919	0.80	0.65	379	1108	1092	1074
7	FLIP 01-6C	1546	999	0.97	0.84	548	1272	1242	1213
8	FLIP 01-48C	1325	922	0.84	0.67	404	1123	1105	1087
9	FLIP 01-51C	1276	825	0.97	0.57	451	1050	1025	1002
10	FLIP 02-4C	1338	863	0.97	0.63	475	1100	1074	1049
11	FLIP 02-47C	1331	838	1.02	0.61	493	1084	1056	1028
12	FLIP 02-49C	1497	892	1.11	0.73	605	1194	1155	1117
13	FLIP 02-59C	1480	770	1.32	0.62	710	1125	1067	1012
14	FLIP 02-69C	1483	1103	0.70	0.89	380	1293	1278	1265
15	FLIP 02-70C	1651	1184	0.78	1.07	467	1417	1398	1379
16	FLIP 02-84C	1660	1028	1.05	0.93	633	1344	1306	1269
17	FLIP 02-85C	1174	971	0.48	0.62	204	1072	1067	1063
18	FLIP 02-86C	1390	848	1.07	0.64	542	1119	1086	1053
19	FLIP 02-88C	1362	945	0.84	0.70	418	1153	1134	1115
20	FLIP 02-89C	1356	1038	0.64	0.77	318	1197	1186	1175
21	FLIP 03-18C	1460	893	1.07	0.71	567	1176	1142	1108
22	FLIP 03-19C	1311	770	1.13	0.55	542	1040	1004	970
23	FLIP 03-25C	1388	929	0.91	0.70	459	1158	1135	1113
24	FLIP 03-29C	1132	873	0.63	0.54	259	1002	994	986
25	FLIP 03-30C	1306	666	1.35	0.47	641	986	932	882
26	FLIP 03-32C	1262	724	1.17	0.50	539	993	956	920
27	FLIP 03-35C	1416	670	1.45	0.52	746	1043	974	910
28	FLIP 03-38C	1145	676	1.12	0.42	469	910	880	850
29	FLIP 03-39C	1163	694	1.11	0.44	469	929	898	869
30	FLIP 03-45C	1310	787	1.10	0.56	523	1048	1015	983
31	FLIP 03-46C	1154	711	1.05	0.45	443	933	906	880
32	FLIP 03-49C	1262	965	0.65	0.66	297	1113	1103	1093
33	FLIP 03-107C	1345	867	0.98	0.64	478	1106	1079	1054
34	FLIP 03-142C	1371	948	0.85	0.71	423	1159	1140	1121
35	FLIP 03-143C	1272	758	1.11	0.53	514	1015	982	950
36	FLIP 03-145C	1602	948	1.12	0.83	654	1275	1232	1191
37	FLIP 03-147C	1379	712	1.33	0.54	667	1046	991	939
38	FLIP 03-148C	1275	711	1.22	0.49	564	993	952	912
39	FLIP 03-152C	1284	900	0.82	0.63	385	1092	1075	1058
40	FLIP 03-153C	1555	928	1.11	0.79	631	1243	1203	1163
41	ILC 3279	1055	708	0.90	0.41	347	881	864	847
	MEAN	1354	861						

Bartlett’s test was used to determine the homogeneity of variances between environments to determine the validity of the combined analysis of variance on the data.The result of Bartlett’s test showed that error variance of Shirvan station was not homogenous with other stations. Therefore combined analysis was done for Kermanshah and Maragheh stations only for two cropping seasons.

Results and discussion

Resistance indices are given in Table 1. High values for MP, GMP, HARM and STI showed that the genotypes ‘FLIP 02-70C’, ‘FLIP 02-84C’, ‘FLIP 02-69C’, ‘FLIP 01-6C’, ’ FLIP 87-59C’ and ‘FLIP 02-89C’ are resistant to drought stress. Genotypes ‘ILC 3279’and ‘FLIP 03-38C’ are susceptible to drought stress as they have low values of TOL and SSI.

Fernandez (1992) studied the yield of genotypes in two environments, with and without drought stress, and divided them in four groups as follows:

5. The genotypes that have high yield in stress and non stress environment (group A).
6. The genotypes that have high yield only in non stress environment (group B).
7. The genotypes that have high yield in stress environments (group C).
8. The genotypes that have weak yield in stress and non stress environments (group D).

Fernandez is of the view that group A can be distinguished from other groups by how high its STI value is in comparison to other genotypes. Selection based on SSI would have some genotypes with low yield under stress but high yield under normal environment. The major drawback of this index is that it is not able to differentiate group A from group C. If the difference between YP and YS is more, TOL increases and this represents increased susceptibility to drought. The index is able to isolate the group A from C. GMP index is less sensitive to the difference in the values of YS and YP. The MP index is based on an arithmetic average, hence when the relative different between YS and YP is great the unbiasedness will be upwards. Therefore GMP is better than MP for separating the different groups.

Table 2:. Correlation coefficient between Yp, Ys and drought tolerance indices

	Yp	**Ys**	**SSI**	**STI**	**TOL**	**MP**	**GMP**	**HARM**
Yp	1							
Ys	0.64**	1						
SSI	0.20 ns	-0.63**	1					
STI	0.87 **	0.93**	-0.29ns	1				
TOL	0.60**	-0.24 ns	0.90**	0.14 ns	1			
MP	0.92**	0.88**	-0.19 ns	0.991**	0.25 ns	1		
GMP	0.88**	0.93**	-0.29 ns	0.997**	0.14 ns	0.994**	1	
HARM	0.83**	0.96 **	-0.39*	0.992**	0.05 ns	0.978**	0.995**	1

The positive correlation between TOL, STI, MP, GMP, HARM and irrigated yield (YP) and negative correlation between TOL and yield under stress (Ys) (Table2) suggest that selection based on TOL will result in reduced yield under well-watered conditions. Similar results were reported by Khayatnezhad *et al*. (2010) and Sio-Se Mardeh (2006). SSI showed a negative correlation with yield under stress (Table 2). SSI has been widely used by researcher to identify sensitive and tolerant genotypes (Clark *et al*. 1992; Sio-Se Mardeh 2006). There was a high significant correlation between STI , GMP, MP , HARM and yield under stress (Table2). The phenotypic correlation of MP, GMP, STI and HARM with seed yield in both stress and non-stress conditions were significant. These criteria are therefore recommended as desirable indices for determination of resistant chickpea genotypes.

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Study on effect of different moisture treatments on yield and some agronomic characters in lentil (*Lens culinaris* L.) genotypes

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Abstract

Drought stress is one of the most important abiotic stresses for rainfed crops in Iran. Most of the lentil area (92 percent) in Iran is rain fed. To investigate the effects of different moisture treatments on yield and some agronomic characters, an experiment was carried out at the Research Station of Ekbatan, in Hamedan province, in a split plot design with four replications during the 2010-2011 cropping season. The main plots had 4 different moisture levels (irrigation at flowering, irrigation at podding, irrigation at flowering and podding, and no irrigation) and the sub-plots had 5 genotypes ('ILL 6037', 'Cabralinta', 'ILL 325', 'ILL 857' and local check). The result showed that the interaction of different moisture treatments and genotypes was significant for all traits except number of primary branches per plant and 100 seed weight. Averaged over all the genotypes, the highest seed yield was obtained with irrigation during podding (1136 kg/ha) and it was 3.6 times than that under check (rainfed). Local check produced highest average seed yield (936 kg/ha). Therefore, it is recommended that for spring planting local cultivar should be grown and it should be irrigated during podding.

Introduction

Lentil (*Lens culinaris* Medikus ssp. *culinaris*) has been an important crop in the highland cropping systems of West Asia and North Africa (WANA) because of its contribution to human food, animal feed and soil health (Sarker *et al*. 2004). Its seed is a rich source of protein (up to 28%) for human consumption, and the straw is a valuable animal feed in Iran. The crop is adapted to less favorable environments, where it is predominantly grown in winter under the annual average rainfall between 300 and 400mm (Sarker *et al*. 2003).

Drought is the most common adverse environment limiting crop production in different parts of the world, especially in Iran which is considered as dry and semi-dry country. Some 49% of cropped area in Iran is planted rainfed due to the limitation of irrigation water. Most of the lentil area (92 percent) is also rain fed (Sabaghpour 2006). Breeding for drought resistance is therefore desirable. However, it is complicated because of the lack of fast and reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions for a large scale genotypes evaluation (Ramirez and Kelly 1998).

Achieving a genetic increase in yield under the stress environments has been recognized to be a difficult challenge for plant breeders while progress in yield gain has been much higher in favourable environments (Richards *et al.* 2002). Drought indices, which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions, have been used for screening drought-tolerant genotypes (Mitra 2001). In this experiment we used various drought tolerance indices to identify drought tolerant genotypes under dry rainfed conditions of Iran. In addition, we investigated the response of selected genotypes to irrigation for enhancing their productivity.

Material and methods

In order to evaluation effects of different of moisture treatments on yield and some agronomic characters in lentil (*Lens culinaris* L.) genotypes, this experiment was conducted during 2010-11 cropping season in a split plot design with four replications at the Ekbatan research station in Hamedan, Iran. The main plots had four irrigation treatments (irrigation at flowering, irrigation at podding, irrigation at flowering and podding, and no irrigation); the sub-plots had five genotypes ('ILL6037', 'Cabralinta', 'ILL 325', 'ILL 857' and local check). Plot size was 4 m^2 (4 m long, 4 rows, 0.25 m apart). Plants were spaced 2 cm apart within rows. Fertilizers were applied prior to ploughing at the recommended rates of 20 kg/ha N and 30 kg/ha P_2O_5. During the vegetative and reproductive phases weeds were controlled. Data on days to flowering, days to maturity, plant height, number of pods per plant, plants wet weight, stem weight, number of secondary branches per plant, number of primary branches per plant, number of seed per plant, 100-seed weight, biological yield, harvest index and seed yield were collected.

In order to evaluate the tolerance of lentil varieties to drought stress, five selection indices including stress susceptibility index (SSI), stress tolerance index (STI), geometric mean productivity (GMP), tolerance index (TOL) and mean productivity (MP) were calculated based on grain yield under drought-stressed and irrigated conditions as described in the earlier chapter (Sabaghpour *et al.* in this volume).

Results and discussion

The result showed that effects of different moisture supply treatments were significant on plant wet weight, biological yield, stem weight, days to maturity, plant height, number of secondary and primary branches per plant, number of seeds and pods per plant, harvest index and grain yield. There were significant differences among the genotypes for all the traits except stem weight, number of primary branches per plant, pod number per plant and 100 seed weight. The interaction moisture treatments × genotypes was significant for all traits except number of primary branches per plant and 100 seed weight.

Table 1: Resistance indices of five genotypes under stress and non-stress environments

Genotype	YP	YS	Tol	SSI	MP	GMP	STI
ILL6037	110.58	32.63	77.95	0.98	71.60	60.06	0.28
Cabralinta	114.25	40.08	74.18	0.90	77.16	67.67	0.35
ILL325	103.93	18.73	85.20	1.13	61.33	44.11	0.15
ILL857	106.00	21.95	84.05	1.10	63.98	48.24	0.18
Local	133.38	44.15	89.23	0.93	88.76	76.74	0.46
Mean	113.63	31.51	82.12	1.01	72.57	59.36	0.28

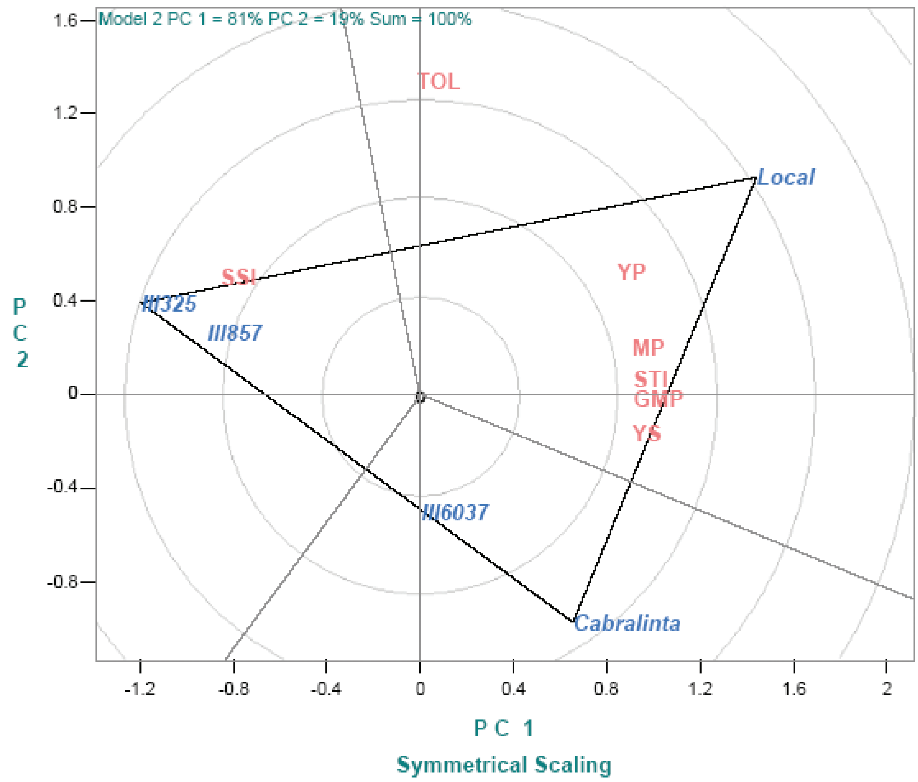

Figure 1: Polygon of the GGE-biplot based on symmetrical scaling for genotypes and drought tolerance indices.

Table 2: Results of factor analysis

CA	Eigen values	Cumulative Eigen values	YP	YS	Tol	SSI	MP	GMP	STI
PC1	4.766	81	0.847	0.907	-0.014	-0.851	0.908	0.916	0.915
PC2	2.299	19	-0.503	0.182	-1.319	-0.488	-0.177	0.036	-0.048

The result showed that the highest yield was obtained with irrigation during podding (1136 kg/ha) which was significantly higher than under other treatments. Irrigation during podding gave 360% higher yield than check (rainfed). The highest seed yield was produced by local check (936 kg/ha) followed by Cabralinta (898 kg/ha) and Bilesevar (816 kg/ha). Therefore, it is recommended that spring planted lentil should be irrigated at the podding stage. Drought stress at the grain filling period is known to dramatically reduce grain yield (Ehdaie and Shakiba 1996). Talebi *et al*. (2009) and Toker and Çagirgan (1998) reported that yield under irrigation was about two times higher than under stress.

Drought resistance indices were calculated on the basis of grain yield of genotypes. Local check and Cabralinta had high STI along with high yield (Table 1).

Analysis of principal components in Table 2 has been done for the first two components. The first component accounts for 81% the variations. In the first principal component analysis of drought resistance indices is shown in Fig1. The result showed that local variety was superior under both stress and non stress environments.

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Influence of water stress on growth, yield and quality of potato (*Solanum tuberosum* L.) under the arid climatic conditions of Central Asia

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Abstract

Threat of drought alarms potato growers under the arid conditions of Central Asia because of the reduced water supply as a consequence of global warming and relative climate change. The International Potato Center (CIP)-Liaison Office of Tashkent has assessed drought tolerance of nine CIP genotypes compared with Dutch variety 'Sante' in the lowlands of Uzbekistan during the second cropping season (July-October) of three consecutive years, 2008-2010. The experimental set up consisted of a factorial strip plot design with three replications and three treatments including a control, with water applied according to local practices, a moderate and a severe water deficit treatments both based on a regular application of water till 40 days after planting (DAP), followed in the first case by two irrigations at 60 and 80 DAP, and in the other case by cut-off irrigation at 40 DAP. Across water regimes CIP-bred clones '388615.22', '397077.16' and '390478.9' showed the highest significant mean tuber yield with clones 397077.16 and 388615.22 having the highest drought tolerance index (DTI >1.0) under moderate water deficit conditions. In particular, CIP-bred clone 388615.22 had also a significant increase of dry matter content under water stress conditions. A significant linear relationship ($R^2 = 0.44$) was found between DTI and harvest index (HI) under moderate water deficit conditions indicating that the ten potato genotypes seemed to spend their last energy in producing tubers. Sante and 397077.16 also showed the highest HI meaning that they allocated relatively more carbon to the tubers under water stress in comparison with the other genotypes. Paired regression analysis among genotypes revealed that dry matter was positively and significantly correlated with starch content under drought stress and non-stress field conditions. More work is needed for quantifying the effects of environment on dry matter concentration and for determining the degree to which the stability of tuber dry matter concentration and of other traits differs among genotypes.

Introduction

Drought is a severe environmental stress that limits agricultural production worldwide and alarms in particular potato growers in the downstream regions of the Aral Sea basin where potatoes are intensively cultivated during the second growing season from July to October and affected by frequent water shortages.

A field definition for drought is a rainless period of sufficient duration that affects the crop and significantly reduces the economic yield. Drought begins when the readily available soil water in the root zone is exhausted (Kramer 1983). Furthermore, drought can be permanent, periodic, or accidental, occurring early, late, or in the middle of the crop season. Drought can be also cumulative or specific and short.

Potato crop requires much water, and in most countries full or supplemental irrigation is necessary for successful production (Fabeiro *et al*. 2001). A good potato crop requires 400 to 800 mm of water, depending on climatic conditions, soils and duration of the growing season. At a plant density of 40,000 plants per hectare, this corresponds to 100 to 200 liters of water per plant per growing season (Haverkort 1982). In the case of the lowlands of Uzbekistan, use of up to 9000 m^3 ha^{-1} has been recommended by local irrigation specialists (Balashev 1968).

Potato may suffer significant yield reductions even under short periods of water stress because of a relatively shallow root zone, but in spite of its sensitivity, it still produces reasonable yields under conditions that can cause other crops to fail (Weisz *et al*. 1994). A potato crop can be difficult to manage because tuber yield and quality can suffer from even brief periods of water stress following tuber set (Lynch *et al.* 1995). However, in some circumstances, potatoes can tolerate limited deficit in irrigation before tuber set without significant reductions in external and internal tuber quality (Shock *et al*. 1992). Stark *et al.* (2006) suggested that under conditions of deficit irrigation management, to mitigate the effects of water stress producers should apply other cultural practices under their control, including change in area under potato cultivation, field choice, variety selection, fertilizers, seed physiological condition, and spacing. On the other hand, there are authors (Martin and Miller 1983; Miller and Martin 1987; Lynch and Tai 1989; Jefferies and MacKerron 1993) who pointed out the existence of potato genotypic variation in terms of tolerance to water stress that can be, therefore, exploited under drought conditions. In this respect, according to Ekanayake (1990) a genotype is considered drought resistant or tolerant when it produces an economic crop within the limits of its production potential under conditions of restricted water availability.

In the present study, the response of ten potato genotypes to drought stress and non-stress field conditions was investigated and the effects on yield components, dry matter accumulation and other plant and tuber properties were studied to identify drought tolerant and high-yielding genotypes among some CIP-bred advanced potato clones characterized by traits of heat and virus resistance. Different water stress conditions have been tested due to the limited and often reduced water supply that may happen anytime during the second growing season, which is the most important in the double cropping system of the lowlands, especially in the regions that are situated in the middle and lower part of the Aral Sea basin. Two water stress treatments have been studied: a moderate water deficit treatment with intervals of irrigation of 20 days after tuber initiation, and cut-off irrigation after tuber initiation. They were conceived to simulate different levels of water depletion, from transient to sharp and continuous, taking into account what is expected to happen in Central Asia in the near future.

Loss of yield is the main concern of plant breeders and they hence, emphasize on yield performance under moisture-stress conditions. But variation in yield potential could also arise from factors related to adaptation rather than to drought tolerance. Thus, drought indices (Mitra 2001), namely Drought Tolerance Index (DTI), providing a measure of drought based on yield loss under water-stress compared to normal conditions were used in the study.

Materials and methods

Trials were done in the fields of the Institute of Vegetables, Melon and Potato, located in the outskirts of Tashkent, Uzbekistan (437 m asl; Latitude: 41°36’, Longitude: 69°14’) from July till beginning of November, during three consecutive years, 2008, 2009 and 2010 (Table 1). The experimental design was a factorial strip plot design (FSPD), replicated three times, with a plot size of 5.25 m^2 (2.1 x 2.5 m), comprising three rows per plot and ten plants per row. Well-sprouted seed size tubers, class E, of 45-55 mm size, were planted at the spacing of 0.70 x 0.25 m (57,142 plants ha^{-1}), between 11 and 12 July of the three consecutive years. Harvest occurred between 30 October (2009) and 4 November (2008).

Soil was sandy clay loam with sand and clay reaching 66.4 and 32.6%, respectively, and total available water holding capacity equivalent to 16%. Rooting depth varied from 22.7 cm of CIP 388611.22 to 25.0 cm of var. Sante and 27.7 cm of CIP 392797.22. The overall average rooting depth was 25.1 cm. Soil pH varied from 7.0 to 7.2. The previous crop was an association of barley and fodder peas.

Among the treatments, the vertical factor was represented by different irrigations regimes, one per each block: $\mathbf{I_1}$=Control, representing current irrigation practices of one irrigation every 5-7 days to mitigate the effects of hot temperatures in July and August; $\mathbf{I_2}$=Moderate water deficit, with water applied as in the Control treatment up to 40 DAP and thereafter only at 60 and 80 DAP; $\mathbf{I_3}$=Severe water deficit, with water applied as above only up to 40 DAP. In the moderate water deficit treatment the intervals of irrigation were adapted to the level of stress observed on the plants. Therefore, an interval of 20 days between successive irrigations after tuber initiation was considered appropriate. In the case of the severe water deficit treatment, on the other hand, the cut-off irrigation after tuber initiation was conceived to simulate an abrupt depletion of water due to drought that occurs periodically in Central Asia. The horizontal factor was represented by 9 CIP-bred advanced clones (388611.22, 388615.22, 388676.1, 390478.9, 391180.6, 397035.26, 397073.16, 397077.16 and 397054.3) belonging to the LTVR (Lowland Tropics Virus Resistant) population, and a standard check represented by Dutch variety Sante, very popular in Uzbekistan. All the genotypes were chosen for their maturity cycle or tuber bulking maturity approaching 100 days. Class Elite seed tubers of var. Sante were imported, while the other seed tubers were produced locally through tissue culture, further minituber production in the screenhouses of the National University of Uzbekistan and two additional seed multiplications in the highlands.

Water was applied by the furrow irrigation method, most common in Central Asia. Each plot was built as a basin with small slopes; there was no outflow from the field. The amount of water in-flow was recorded using 90° degree V-notch weir flumes, which were located in each block. For each flume, a calibration curve was available, which allowed the calculation of the amount of in-flow water. A tensiometer to measure soil moisture was placed at 30 cm depth along the ridges, every two plots and per replication for a total of 45 tensiometers evenly covering the trial. In the control, water was applied when tensiometer reading was between 40 and 45 kPa and cut off when tensiometer reading was less than 20 kPa.

Fertilization consisted of ammonium sulfate (10 g linear $meter^{-1}$: 30 kg N ha^{-1}), monoammonium phosphate (30 g linear $meter^{-1}$, that is 43 kg N + 197 kg P_2O_5 ha^{-1}) and potassium chloride (17.5g linear $meter^{-1}$ or 250 kg ha^{-1}, that is 150 K_2O) applied before planting along the rows and thoroughly mixed with the soil. An additional amount of ammonium nitrate (10 g linear $meter^{-1}$: 47 kg N ha^{-1}) was incorporated with the second earthing up. Pest control concerned uniquely Colorado potato beetle (*Leptinotarsa decemlineata*, Say) against which Confidor and Gaucho (*imidacloprid*: 70.0 and 58.5%, respectively) were alternatively sprayed for a total of three sprays at the rate of 0.16 kg of commercial formulation per hectare. The crop was dehaulmed manually at 100 DAP because CIP genotypes (*S. tuberosum* x *andigena*) always show a persistent green vegetation under long day conditions even if tubers are already set. Harvest occurred 10-15 days later.

The mean, minimum and maximum temperature, relative humidity (RH), photosynthetic active radiation (PAR), and rainfall were collected from the HOBO meteorological station (Table 1) during the cropping period, while ETo was calculated using the special FAO software (Anonymous 2012).

Table 1: Meteorological data

	2008				2009				2010			
	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
RH (%)	25.4	26.3	31.6	54.7	35.3	42.4	51.3	51.6	44.8	45.9	51.4	57.9
Rainfall (mm)	0	0	11.2	36.6	0	7.8	10.8	2.4	4.6	1.6	4.8	7.2
No. of rainy days	0	0	2	8	0	2	2	1	1	2	2	4
Sunshine hours	12	11.3	10.8	8.6	11	11.3	9.7	7.6	10.7	9.6	10.9	9.1
PAR (uE), mean	568	490	400	305	582	481	414	337	571	486	381	261
Max air temp. (°C)	37.9	37.4	29.8	21.1	37.7	37.5	31.9	31.9	39.3	38.3	36.7	32.4
Min. air temp. (°C)	20.4	18.7	12.6	8.4	14.7	13.9	10.5	1.6	14.7	12.4	7.5	-0.2
Mean air temp. (°C)	29.1	28.0	21.2	14.7	26.2	25.7	21.2	16.7	27.0	25.3	22.1	16.1
ETo (mm/day)	7.1	6.7	5.2	3.7	6.9	6.5	5.3	3.8	6.7	5.7	4.5	3.9

During the three years, plant height and plant canopy were measured following the CIP's International Cooperators' Guide (Anonymous 2007). For plant canopy, the proportion of the ground covered with green leaves was estimated at 50, 70 and 90 DAP using a grid (measuring a multiple of the plant pattern: 75 cm x 70 cm), divided into 7.5 x 7.0 cm cells. The grid was held over the central row (cowering three plants, always the same) of a plot and the number of cells at least half-filled by vegetation were counted and then divided by the total number of cells to determine the percent cover.

The Harvest Index (HI: ratio of tuber dry weight by total biomass on a dry weight basis) was calculated at 100 DAP. At harvest, data were gathered on number of plants harvested, tuber yield (t ha^{-1}), tuber weight plant^{-1} (kg), mean tuber weight (g), number of tubers plant^{-1}. Only HI and Drought Tolerance Index (DTI) were analyzed ignoring the Drought Susceptibility Index (DSI) that according to Clark *et al.* (1992) and Ramirez and Kelly (1998) has shown limitations in wheat and common bean, respectively, because it does not differentiate enough between potentially drought-tolerant genotypes and those that possess low overall yield potential. On the contrary, as *Fernandez (1992*) argued, DTI is more suited to discriminate genotypes with high yield and stress tolerance potentials. DTI was calculated using the following formula (Parameshwarappa and Salimath 2008; Shirinzadeh *et al.* 2010): DTI = $Y_{pt} \times Y_{st}/(Y_p)^2$, where Y_{st} = Yield of cultivar under moisture stress conditions, Y_{pt} = Yield of cultivar under irrigated conditions, and Y_p = Mean yield of all cultivars under irrigated conditions. This index provides a measure of relative drought tolerance based on minimization of yield loss under drought. Values >1.0 indicate greater than average drought tolerance, while values <1.0 indicate greater than average drought susceptibility.

The dry matter (%) and starch (%) content of randomly harvested and separately kept fresh tubers was studied at the biochemical laboratory of the State Committee for Variety Testing, Tashkent, immediately after harvest. The percentage tuber dry matter was estimated by sampling 5 g of at least five tubers with a cork borer, cutting the samples into slices <1 mm thick and drying them at 100°C for 48 hours. On the other hand, starch content was determined by Ewers' polarimetric method (Anonymous 1997)**.**

The data were statistically processed using statistical software CROPSTAT for Windows (McLaren, 2007). A simple analysis of variance (ANOVA) was carried out on the average performance of the ten entries during the three years and means were compared by a LSD test for the levels of significance of α=0.05. The effects of different water regimes (I), the genotype (G), and the interactions Genotype x Water Regime (G x I), Year x Water Regime (Y x I), Year x Genotype (Y x G) and Year x Genotype x Water regime (Y x G x I) were analyzed by combined ANOVA during the three years. Correlations, regression and paired regression analyses between different parameters and per each potato genotype were done when applicable.

Results and discussion

The results show that crop development and yield are adversely affected by continuous or transient water deficit after initial water application till tuber initiation stage. The effects of drought stress on vegetative growth were amplified by the high temperatures recorded that had undoubtedly influenced photosynthesis (Schapendonk *et al.* 1989). Under such extreme conditions, however, genetic variation for drought tolerance has been observed.

Paired regression analyses of all the observed plant parameters across potato genotypes and per each one of them helped in getting a better understanding of the relationship between potato growth and its yield and quality components when a potato crop undergoes water stress under the arid and semi-arid conditions of Central Asia.

Weather conditions

The growing season air temperature in all experimental years was warmer than the 11-year average (Fig. 1). The year 2008 was hotter and drier than the other years in July and part of August because less water was available for the experiment, but in general rainfall was near normal (Table 1). Plant available soil water in the control block at no time fell below the 50% limit in the growing season.

Amount of water applied in the different treatments

The number of irrigations and the amount of water delivered at each irrigation are shown in Table 2 for each year. In the control treatment, designated as $\mathbf{I_1}$, nine, twelve and nine irrigations were applied in 2008, 2009 and 2010, with the delivered water amounting to 812, 900 and 939 mm ha^{-1}, respectively (Table 2). In the moderate water deficit treatment or $\mathbf{I_2}$, five, eight and six irrigations were applied amounting to 514, 688 and 546 mm ha^{-1} of water respectively. In the severe water deficit treatment or $\mathbf{I_3}$, four, six and four irrigations were applied amounting to 382, 535 and 448 mm ha^{-1} of water respectively. The amounts applied in the control treatment or $\mathbf{I_1}$ appear higher than the figures reported by Haverkort (1982), but they seem justified if we consider the temperatures of the months of July and August (Table 1).

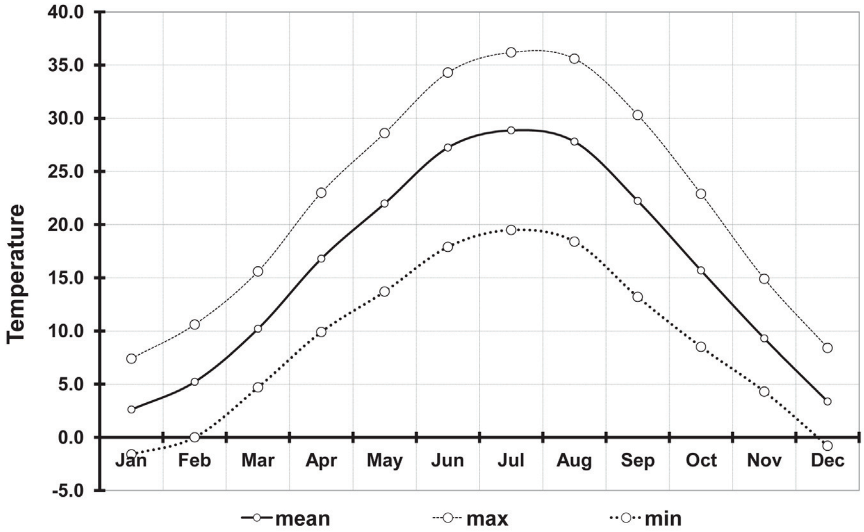

Figure 1: Average temperature (^{0}C) of eleven years (1997-2007) in Tashkent.

Table 2: Total water delivered and stored/percolated in each treatment.

Year	Irrigation level	No. of irrigations	Water stored in the root zone and percolated (mm ha^{-1})
2008	Normal irrigation	9	812
	Moderate deficit	5	514
	Severe deficit	4	382
2009	Normal irrigation	12	900
	Moderate deficit	8	688
	Severe deficit	6	535
2010	Normal irrigation	9	939
	Moderate deficit	6	546
	Severe deficit	4	448

Performance ability of potato genotypes

Plant height: Combined analysis of variance showed that with increasing stress intensity plant height decreased significantly, so that mean plant height at 75 DAP ranged from 76.7 cm at optimum irrigation to 67.5 and 65.7 cm at moderate and severe water stress, respectively (Table 3). Plant height reduction with increasing water deficit was less marked on 397054.3 (-7.5 cm), 397077.16 (- 6.8 cm) and 397073.16 (-6.5 cm). Analysis over years indicated that plant height across treatments was shorter in 2008 (56.6 cm) than in 2009 (74.2 cm) and 2010 (79.1 cm). This may be due to the drier season in 2008 in comparison with the other years (Tables 1, 2). Clone

397054.3 had the highest mean height in 2009 (93.0 cm) and 2010 (100.7 cm), while 388615.22 was significantly the tallest in 2008 (70.8 cm).

Table 3: Effect of different irrigation regimes on plant height (means of 3 years) at 75 DAP

Entries	Plant height (cm)			
	Normal irrigation	**Moderate water deficit**	**Moderate water deficit**	**Mean**
Sante	70.6	65.1	61.1	65.6 cd
388611.22	83.4	69.3	65.0	72.6 abc
388615.22	86.2	75.2	74.8	78.7 ab
388676.1	73.8	64.5	61.4	66.6 bcd
390478.9	74.5	65.2	61.4	67.0 bcd
391180.6	71.9	64.2	62.4	66.2 cd
397035.26	81.8	72.8	66.5	73.7 abc
397073.16	65.3	55.9	58.8	60.0 d
397077.16	71.0	65.0	64.2	66.7 bcd
397054.3	88.8	77.9	81.3	82.7 a
Mean	76.7	67.5	65.7	
LSD (0.05)	12.9	12.5	14.7	
Entries (G)	12.39**			
Irrigation (I)	4.13**			

Table 4: Effect of different irrigation regimes on plant canopy (means of 3 years) of different potato lines at different stages of growth

Entries	Plant canopy (%)											
	50 DAP			**Mean**	**70 DAP**			**Mean**	**90 DAP**			**Mean**
	I_1	I_2	I_3		I_1	I_2	I_3		I_1	I_2	I_3	
Sante	54.4	42.4	42.7	46.5 abc	78.2	61.7	53.6	64.5 ab	57.5	41.0	35.5	44.7 b
388611.22	57.3	42.5	39.6	46.5 abc	84.5	64.4	57.3	68.7 ab	75.9	54.4	52.1	60.8 ab
388615.22	43.4	39.9	41.6	41.6 bc	79.5	63.9	56.2	66.5 ab	85.3	55.6	54.6	65.2 ab
388676.1	45.5	42.4	38.1	42.0 bc	72.9	59.8	51.0	61.2 b	70.0	59.3	46.1	58.5 ab
390478.9	62.1	51.9	53.0	55.7 a	84.5	70.9	66.9	74.1 a	79.4	52.8	41.3	57.8 ab
391180.6	53.9	40.8	48.2	47.6 ab	76.0	60.6	63.3	66.6 ab	65.1	48.4	47.7	53.7 ab
397035.26	47.3	39.4	35.2	40.6 bc	72.6	61.8	50.1	61.5 b	75.8	60.9	50.5	62.4 ab
397073.16	47.7	42.4	35.7	41.9 bc	68.8	60.2	49.6	59.5 b	73.0	61.1	52.4	62.1 ab
397077.16	48.1	47.1	40.9	45.4 abc	75.7	63.1	54.7	64.5 ab	71.6	61.3	55.0	62.6 ab
397054.3	40.9	32.4	32.1	35.1 c	66.4	56.9	48.4	57.2 b	82.3	63.3	58.8	68.1 a
Mean	50.1	42.1	40.7	44.3	75.9	62.3	55.1	64.4	73.6	55.8	49.4	59.6
LSD (0.05)	9.5	11.9	8		13.7	10.5	7.4		19.2	24.6	21.9	
Entries (G)	11.7**				12.3**				21.0*			
Irrigation (I)	3.9**				4.1**				7.0**			

I_1=Normal irrigation, I_2=Moderate water deficit, I_3=Severe water deficit

Plant canopy: Combined ANOVA revealed that plant canopy decreased significantly with the increase of water deficiency all along the growing cycle. Furthermore, there was a significant variation among entries during all growing cycles, although it was less marked at 90 DAP due to the approach of plant maturity stage for Sante compared with the other genotypes that maintain a persistent vegetation under long photoperiod even if tubers are already set (Table 4). At 70 DAP, 390478.9 had the mean largest plant canopy (74.1%), followed by 388611.22 (68.7%), 391180.6 (66.6%), 388615.22 (66.5%), 397077.16 and Sante (64.5%). Interaction G x I was not significant. On the contrary, the interactions G x Y and I x Y were highly significant. Clone 390478.9 was the only one which had always the best mean canopy at 50 (55.7% vs. overall mean of 44.3%), 70 (74.1 vs. 64.4%) and 90 DAP (57.8 vs. 59.6%). However, the more abundant vegetative biomass of this clone compared with the others might have required more stomatal control in the case of frequent dry spells with consequent reduction of transpiration and subsequently photosynthesis and yield (Haverkort 1982). Taking into account that respiration is also supposed to increase with temperature as it is estimated to roughly double per each 10°C increase between 10°C and 35°C (Sale 1973) and that temperatures above 30°C provoke the decline of the rate of net photosynthesis (Leach *et al.* 1982; Thorntorn *et al.* 1996), the assimilate production should have been reduced under the hot environments in Tashkent lowlands (Table 1). However, in spite of those constraints the mean yield of CIP 390478.9 has been among the highest in the trials (Tab. 5). Similar considerations are valid for clone 397077.16, which had one of the best plant canopies at 50, 70 and 90 DAP and a significant average yield (Table 5).

Table 5: Effect of different irrigation regimes on harvest variables of different potato lines (means of 3 years)

Entries	Harvest variables															
	Tuber yield (t/ha)			Mean	Mean tuber weight (g)			Mean	Tuber weight/ plant (kg)			Mean	No. of tubers/ plant			Mean
	I_1	I_2	I_3		I_1	I_2	I_3		I_1	I_2	I_3		I_1	I_2	I_3	
Sante	33.9	23.6	21.1	26.2 bc	73.2	66.7	55.3	65.1 b	0.593	0.406	0.370	0.456 ab	8.7	6.9	7.2	7.6 ab
388611.22	31.7	23.1	17.8	24.2 bc	67.3	51.9	41.8	53.7 bc	0.554	0.375	0.313	0.414 b	8.2	7.5	7.3	7.7 ab
388615.22	36.5	32.5	20.3	29.8 a	118.3	75.2	56.5	83.3 a	0.629	0.528	0.355	0.504 a	5.6	7.3	6.5	6.5 b
388676.1	27.0	21.7	17.3	22.0 c	66.6	61.6	44.5	57.6 bc	0.473	0.341	0.304	0.373 c	7.8	5.9	7.1	6.9 ab
390478.9	32.9	26.4	20.1	26.5 ab	83.4	50.0	43.3	58.9 bc	0.576	0.414	0.352	0.447 ab	7.3	8.4	7.9	7.9 a
391180.6	24.0	22.3	18.8	21.7 c	64.6	48.7	47.4	53.6 bc	0.419	0.367	0.329	0.372 c	6.8	7.5	7.6	7.3 ab
397035.26	31.9	22.5	17.2	23.9 bc	71.5	47.7	38.1	52.4 bc	0.557	0.362	0.300	0.406 b	7.8	7.8	7.8	7.8 a
397073.16	29.7	21.4	16.6	22.6 c	70.0	42.1	43.6	51.9 bcd	0.520	0.369	0.289	0.393 bc	8.0	8.9	6.5	7.8 a
397077.16	33.7	27.5	20.1	27.1 ab	78.2	57.1	57.3	64.2 b	0.590	0.460	0.352	0.467 ab	7.8	8.2	6.3	7.4 ab
397054.3	25.6	18.3	16.8	20.2 d	75.5	48.7	43.7	56.0 bc	0.449	0.263	0.294	0.335 cd	6.5	5.3	6.3	6.0 b
Mean	*30.7*	*23.9*	*18.6*		76.9	55.0	47.2		0.536	0.389	0.326		7.4	7.4	7.0	
LSD (0.05):																
Entries (G)	3.3**				8.3**				0.089**				1.2*			
Irrigation (I)	1.8**				4.6**				0.045**				ns			

I_1=Normal irrigation. I_2=Moderate water deficit. I_3=Severe water deficit

Tuber yield: Across genotypes, mean tuber yield decreased significantly as water stress increased (Tab. 5). On overall average, the most significant tuber yields were reported for 388615.22 (29.8 t ha^{-1}), 397077.16 (27.1 t ha^{-1}) and 390478.9 (26.5 t ha^{-1}). CIP clone 388615.22 was the only one which always recorded the highest yield (G x Y) during the three years, while the highest mean tuber yield was always recorded in the control treatment (Y x I) with 388615.22 (36.5 t ha^{-1}). Interactions G x I and Y x G x I were not significant. In general, if water stress would occur after tuber initiation, as it was in this study, then partitioning to tubers is promoted and maturity is advanced accordingly (Jefferies, 1995). This was valid for some CIP genotypes like 397077.16, 388611.22, 388615.22 and 397054.3 that are usually harvested a bit later and the cycle of which was advanced of approximately 10 days in this experiment. During the three years these genotypes used 583 and 455 mm of water (Table 2) on average under moderate and severe water deficit, respectively, representing on a per hectare basis some 5 830 and 4 550 tons of water. A crop yielding 23.9 and 18.6 t ha^{-1} (Table 5) under the proposed water stress conditions would therefore use approximately 243.9 and 244.6 tons of water to produce each ton of potatoes.

Mean tuber weight: On average (Table 5), clone 388615.22 had the highest significant mean tuber weight (83.3 g), during the 3-year experiment (G x Y). It was, however, the one which showed the most significant decrease of mean tuber weight (I x G) across different irrigation regimes. In the moderate water deficit treatment (I_2) we can observe a high incidence of small-sized tubers and a decrease of mean tuber weight. This can be probably explained by a strong competition among the tubers for assimilates when irrigation was restored, as it was observed by Harris (1978). Also for this variable, the interaction Y x G x I was not significant.

Tuber weight plant $^{-1}$: Water stress reduced tuber fresh weight per plant in all the entries (Tab. 5). On average, clone 388615.22 had the highest mean plant tuber weight (0.504 kg), followed by 397077.16 (0.467 kg), Sante (0.456 kg) and 390478.9 (0.447 kg). In each year of experimentation this variable was very much influenced by the water irrigation regime (Y x I). Clone 388615.22 and var. Sante had the best performance in terms of tuber weight plant^{-1} every year (Y x G). For this variable, the interactions G x I and Y x G x I were not significant.

Number of tubers plant $^{-1}$: On average, the highest mean number of tubers plant^{-1} (7.9) was produced by clone 390478.9; however, only 388615.22 (6.5) and 397054.3 (6.0) produced a less significant number of tubers (Tab. 5). Generally, a lower number of tubers plant^{-1} did not correspond to a decreased amount of water. There were, however, some genotypic differences (G x I) characterizing: (a) Sante, which showed a significantly higher number of tubers plant^{-1} under non-stress than water stress conditions, (b) 397073.16 and 397077.16 that did not show any significant differences in the number of tubers plant^{-1} under moderate water stress and control conditions, (c) 388676.1, which showed similar performance under control and severe water deficit, (d) 388615.22, which had better performance under both water stress rather than non-stress conditions. Therefore, the effects of drought were not so noticeable in general as they affected plants later than the critical stage identified with tuber initiation. Most probably, the high temperatures in July and August had a more marked effect than water stress on the number of tubers plant^{-1}. This was also noticed by Wheeler *et al.* (1986) and Snyder *et al.* (1989) who underlined the negative effects of high temperature on tuber induction and initiation that are more marked under long photoperiods.

Across genotypes, mean tuber weight significantly decreased with increase of water stress. CIP-bred clone 388615.22 had the highest significant mean tuber weight (83.3 g), emerging as the best under moderate water deficit (75.2 g) and second (56.5 g) after 397077.16 (57.3 g) under severe water deficit conditions. It was, however, the most susceptible to drought with a mean tuber weight significantly decreasing across water irrigation regimes. Tuber yield plant^{-1} was also reduced across water irrigation regimes. A minimum tuber yield reduction equivalent to 7.1 and 21.7% was recorded for 391180.6 under moderate and severe water deficit compared with control, respectively, while the highest percentages were recorded for Sante (-30.4%) and 397035.26 (-46.1%), under moderate and severe water deficit, respectively (Table 5). When tuber yield performance under severe water deficit was compared with moderate water deficit, the least yield reduction was noticed for 397054.3 (8.2%), followed by Sante (10.6%), meaning that for these two genotypes yield reduction was not so noticeable under different water stress conditions, probably due to soil characteristics. Generally, the number of tubers plant^{-1} was less influenced by the water regimes studied than by the high temperatures recorded although some genotypic differences were noticed.

Harvest Index: Drought stress did not affect HI considerably. The highest harvest index of 0.82 was for Sante under optimum irrigation conditions (Table 6). The same variety had also a high HI under moderate (0.78) and severe water deficit (0.78), but it was not significantly higher than that of 397077.16 (0.76, 0.79), indicating that both genotypes allocate relatively more carbon to the tubers than the other entries did under water stress. In this case it seems that the plant strategy is oriented towards advantaging tubers (Dalla Costa *et al.* 1997).

Table 6: Harvest Index of different potato lines at 100 DAP as affected by moisture supply

Entries	Average of 3 years (2008-2010)			
	Normal irrigation	Moderate water deficit	Severe water deficit	Mean
Sante	0.82	0.78	0.78	0.79 a
388611.22	0.63	0.69	0.69	0.67 bc
388615.22	0.67	0.71	0.71	0.70 b
388676.1	0.67	0.67	0.64	0.66 c
390478.9	0.69	0.68	0.68	0.68 bc
391180.6	0.71	0.70	0.71	0.71 b
397035.26	0.59	0.58	0.64	0.60 d
397073.16	0.68	0.72	0.69	0.70 b
397077.16	0.69	0.76	0.79	0.75 ab
397054.3	0.61	0.54	0.47	0.54 e
Mean	0.67	0.68	0.68	0.68

The same clone 397077.16 and clones 388611.22, 388615.22, 397035.26 and 397073.16 showed a decrease in HI as irrigation increased meaning that more biomass is partitioned to leaves and stems resulting in a drop in HI that was more important for 397077.16 (0.10) than for the other clones when the severe water deficit is compared with normal irrigation. This decrease in harvest index with increased irrigation has been also observed by Susnoschi and Shimshi (1985) and Onder *et al.* (2005). In particular for clones 388615.22, 397073.16 and 397077.16 HI was higher under drought than under well-watered conditions, while it was the opposite for

388676.1. Schafleitner *et al.* (2009) obtained the same results working on the same clones and concluded that allocation of sugars to tubers varies under drought and changes in HI occur in a genotype-dependent manner. Analysis of variance of the harvest index showed significant differences ($\alpha<0.05$) between means for the main effect genotype, but not for the irrigation regimes. Interactions were also not significant apart from I x Y. In general, mean HI changed little (0.1) between drought treatments and normal irrigation, confirming the results reported by other authors (Jefferies and MacKerron 1987; Gregory *et al.* 1992).

Table 7: Drought Tolerance Index (DTI) of different potato lines calculated on tuber yield basis (t ha^{-1}), mean value of 3 years

	Drought Tolerance Index	
Entries	**Moderate water deficit**	**Severe water deficit**
	Mean	**Mean**
Sante	0.994	0.725
388611.22	0.710	0.450
388615.22	1.251	0.734
388676.1	0.589	0.460
390478.9	0.839	0.541
391180.6	0.861	0.537
397035.26	0.832	0.542
397073.16	0.790	0.545
397077.16	1.294	0.854
397054.3	0.477	0.357
Mean	*0.864*	*0.574*

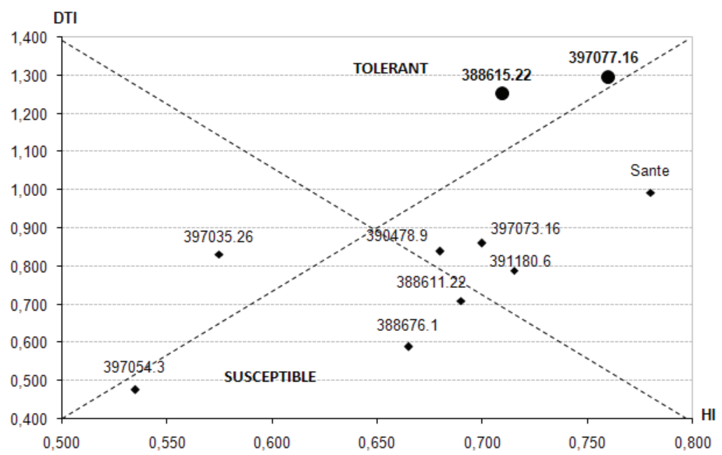

Figure 2: Correlation between HI and DTI under moderate water deficit conditions.

Drought Tolerance Index (DTI): Mean DTI values ranged from 0.477 and 0.357 (397054.3) to 1.294 and 0.854 (397077.16), under moderate and severe water deficit, respectively. The highest mean values under moderate and severe water deficit conditions (Table 7) were recorded both with 397077.16 (1.294 and 0.854, respectively) and 388615.22 (1.251 and 0.734, respectively), although their values were significant only in the case of moderate water stress. Figure 2 refers to the correlation between DTI and HI for mean values of 3 years of experimentation under moderate water deficit conditions. It clearly shows how discriminations exist between less and more tolerant genotypes, confirming previous assessment. Clones 397077.16 (HI = 0.760 and DTI = 1.294) and 388615.22 (HI = 0.710 and DTI = 1.251) were the most tolerant genotypes to drought under moderate water deficit, while 397054.3, 388676.1 and 388611.22 the most susceptible ones. The correlation was positive and equivalent to r = 0.66.

Based on these results should we conclude as Haverkort and Goudriaan (1994) did that the higher the HI the earlier is the crop type because it looks like an escape of later drought from the earlier genotypes? Those CIP clones might have reacted as early types, but under long photoperiod and optimum irrigation they normally behave as mid-early or medium types with persistent and green vegetation although tubers are already set.

A significant linear relationship (Fig. 3) was found between DTI and HI under moderate water deficit conditions in varieties with HI from 0.54 to 0.78 and DTI from 0.47 to 1.294 (Table 7) with an equation: y = -0.73320 + 2.33807 x, explaining 44% of the variation of DTI (R^2). As predicted, for a potato entry whose HI is 0.78 (Sante), DTI is 1.09 (y = -0.73320 + 2.33807 x 0.78). In reality, it approaches (0.994; Table 7). Therefore, when affected by moderate or transient drought the ten potato entries seemed to spend their last energy in producing tubers. This study indicates that a high above ground dry matter yield also means a high tuber yield.

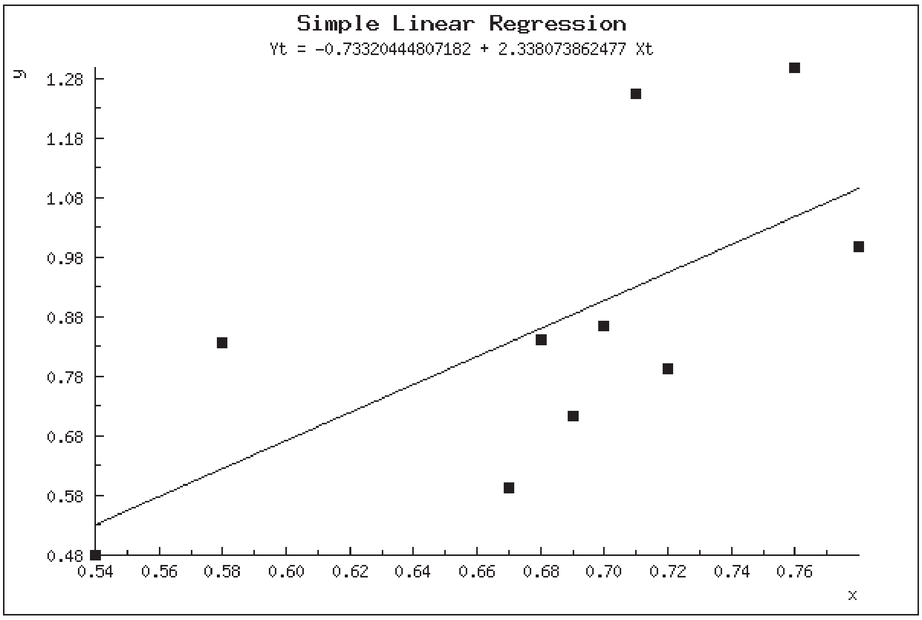

Figure 3: Linear regression between HI (x) and DTI (y) under moderate water deficit conditions (R^2 = 0.4408; F test = 0.31*).

Dry matter content: The highest and most significant increase of dry matter was recorded in 397073.16 (23.1%) and 388615.22 (22.7%) as shown in Table 8. The percent dry matter in tubers markedly increased with the increased water stress as also previously found by Levy (1983) and

Jefferies and MacKerron (1993). The latter authors stated that in drought-affected crops, tuber dry matter concentration increases because tuber water content is influenced to a greater extent than dry matter accumulation. However, the non-significant interaction G x I makes our conclusion less convincing. Jefferies and MacKerron (1993) stated that cultivars that show the least change in tuber dry matter concentration will exhibit the greatest drought tolerance. Therefore, according to them, the selection of genotypes for stability in dry matter concentration over a range of soil moisture conditions may contribute towards increased drought tolerance. Alternatively, the same authors in 1989, in an experiment with potato plants irrigated or water-stressed from plant emergence, remarked that the reduction in dry-matter accumulation in drought-affected crops was attributed primarily to lower interception of radiation as a result of reduced leaf expansion and the suppression of branching. This was not the case in our experiment because drought intervened later. The drought stress occurring in the severe water deficit treatment (I_3) probably led to the extraction of water from tubers as reported by Moorby (1978). In fact, this treatment achieved the highest mean tuber dry matter content (22.4% vs. 21.3 and 21.8% for the control and the moderate water deficit treatment, respectively) and mostly reduced fresh matter yield.

Table 8: Effect of different irrigation regimes on biochemical composition of different potato lines (mean of 2 replications)

Entries	**Biochemical composition**							
	Dry matter (%)			**Mean**	**Starch (%)**			**Mean**
	I_1	I_2	I_3		I_1	I_2	I_3	
Sante	21.1	21.7	22.1	21.6 cd	14.0	17.1	20.1	17.1 g
388611.22	21.9	22.5	23.2	22.5 bc	14.7	17.8	20.7	17.7 f
388615.22	22.2	22.7	23.3	22.7 ab	16.2	19.0	22.0	19.1 a
388676.1	20.1	20.3	20.9	20.4 e	13.1	16.1	19.2	16.1 h
390478.9	22.2	22.4	22.9	22.5 bc	16.3	18.8	21.7	18.9 b
391180.6	21.5	22.0	22.3	21.9 bc	15.2	18.0	21.1	18.1 ef
397035.26	20.1	21.0	21.5	20.9 de	14.1	17.1	20.1	17.1 g
397073.16	22.8	23.0	23.6	23.1 a	15.6	18.1	21.0	18.2 d
397077.16	21.8	22.1	22.8	22.2 bc	15.8	18.4	21.7	18.6 c
397054.3	19.7	20.5	21.6	20.6 e	13.7	18.2	21.3	17.7 f
Mean	*21.3*	*21.8*	*22.4*	*21.8*	*14.8*	*17.9*	*20.9*	*17.9*
LSD (0.05)	0.8	0.8	0.9		0.1	0.1	0.1	

Due to the insignificant interactions G x Y and G x Y x I we could not apply in our study the indications given by Killick and Simmonds (1974) who concluded that genotype-by-environment effects on the specific gravity of tubers, and hence tuber dry matter concentration, may be more influenced by effect of years than of location, perhaps suggesting a greater effect of differences in water stress between years than of other environmental effects differing between locations. Positive correlations were found between tuber dry matter content (%) and canopy cover at 70 DAP (%); in other words, by increasing the ground cover, tuber dry matter content increases at the same time, although the latter was not totally ground cover dependent, but partially, as it is shown in Figure. 4 ($r = 0.48$; $r = 0.53$; $r = 0.36$, under control, moderate and severe water deficit conditions, respectively).

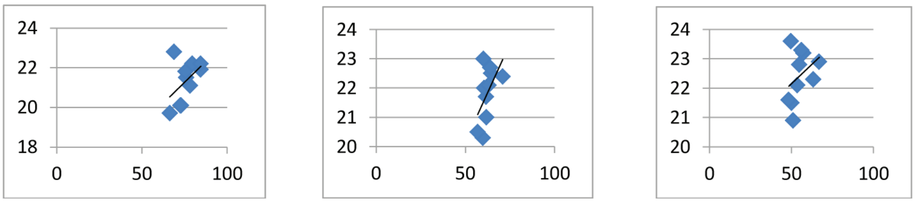

Figure 4: Correlations between tuber dry matter content (%) and canopy cover (%) of plants at 70 DAP under different irrigation regimes.

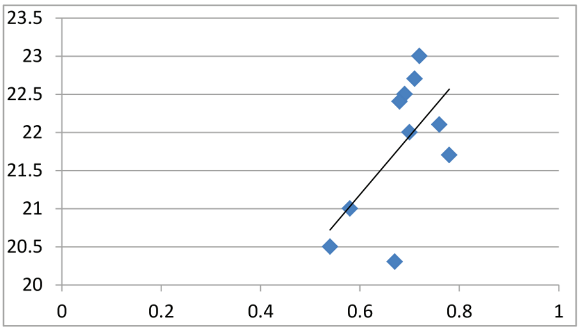

Figure 5: Correlation between HI and dry matter content under moderate water deficit conditions.

There was also a positive correlation (r= 0.61) between HI and dry matter content under moderate water deficit conditions as it is shown in Figure 5, meaning that for each increase of HI, dry matter content rises as well. CIP clones 397077.16 and 388615.22 were identified as the most promising genotypes for tolerance to drought, based on their high DTI under moderate water deficit (1.294 and 1.251, respectively). CIP clone 388615.22, which was initially selected for traits of resistance to heat and viruses had also a significant increase of dry matter content in the tubers under water stress conditions similarly to the other clones although their values were not significant (α>0.05) as it can be seen in Table 8. The capacity of 388615.22 and 397077.16 to accumulate dry matter in tubers under such conditions might be useful in the evaluation of genotypes better adapted to water stress.

Starch content (%): This variable increased as the water stress increased (Table 8). The highest (19.1%) and lowest (16.1%) mean values of this variable were recorded for clones 388615.22 and 388676.1, respectively. Interaction G x I was significant showing that starch content increases with increasing water stress conditions confirming findings of Davies *et al.* (1989). On the contrary, Geigenberger *et al.* (1999) observed, although in wild-type tubers, that water stress stimulates sucrose and inhibits starch synthesis. In accordance with König (2009), we can deduce that the high dry matter content resulting in high starch content at the time of harvesting was influenced by weather conditions, with an abundance of sunshine promoting photosynthesis as well as drought in the last part of the vegetation period and by the absence of potassium supplied by fertilizers. In the paired regression analyses studied further we could observe how starch and dry matter content were positively and significantly correlated under water stress and non-stress field conditions.

Relationships between parameters across genotypes

Paired regressions were analyzed across genotypes for a number of parameters under different water stress and non-stress conditions. The dry matter content was always considered the independent variable (X), which was correlated with the other traits (Y).

Dry matter content was positively and significantly correlated (Table 9) with number of tubers plant^{-1} ($P<0.01$), tuber weight plant^{-1} and starch content ($P<0.05$). The equations of regression and the respective coefficients of determination were:

Number of tubers plant^{-1} $y = -13.166 + 0.941x$ ($R^2 = 0.63$)

Tuber weight plant^{-1} $y = +0.048x$ ($R^2 = 0.41$)

Starch content $y = +0.628x$ ($R^2 = 0.44$).

Some positive tendency was observed for plant canopy ($r = 0.24$), plant height ($r = 0.40$), tuber yield ($r = 0.54$), and harvest index ($r = 0.61$).

In the paired regressions analyzed under the other treatments (Tables. 10, 11) dry matter content was positively and significantly correlated with starch content under severe water deficit ($R^2 = 0.48$; $P<0.05$) and normal irrigation conditions ($R^2 = 0.74$; $P<0.01$), with regression equations being: $y = +0.682x$ and $y = +0.912x$, respectively, because the intercepts were not significant.

Table 9: Paired regressions between Dry Matter Content (X) and other traits (Y) of the potato entries under moderate water deficit conditions

Variables	Correlation Index	Fisher's test	R^2	Slope	Intercept	Equation of a regression
Plant height	0.40	1.52 (ns)	0.16	- 2.75614		
Plant canopy (90 DAP)	0.24	0.49 (ns)	0.06	- 1.79529		
Tuber Yield	0.54	3.42 (ns)	0.30	2.323951		
Mean tuber weight	0.001	1.98E-05 (ns)	2.48E-06	- 0.01714		
No. of tubers/plant	0.79	13.6 **	0.63	0.941146**	-13.166*	y = - 13.166 + 0.941 x
Plant tuber weight	0.64	5.47 *	0.41	0.04849*	- 0.669 (ns)	y = +0.048 x
Starch content	0.67	6.42 *	0.44	0.627943*	4.158 (ns)	y = + 0.628 x
Harvest Index	0.61	4.69 (ns)	0.37	0.048158		

* P < 0.05; ** P < 0.01; ns = not significant.

Relationships between parameters within each genotype

In the case of paired regressions per genotype, the analyses took into account only the treatment under moderate water deficit conditions. They revealed that dry matter content (X) was positively and significantly correlated with plant height for CIP 388676.1, plant canopy for CIP 388615.22, tuber yield for CIP 397035.26 and tuber weight plant^{-1} for CIP 391180.6 (Table 12). The respective equations were as follows:

Table 10: Paired regressions between Dry Matter Content (X) and other traits (Y) of the potato entries under severe water deficit conditions

Variables	Correlation Index	Fisher's test	R^2	Slope	Intercept	Equation of a regression
Plant height	0.15	0.18 (ns)	0.02	- 1.18912		
Plant canopy (90 DAP)	0.17	0.23 (ns)	0.03	1.326099		
Tuber Yield	0.28	0.67 (ns)	0.08	0.523957		
Mean tuber weight	0.27	0.61 (ns)	0.07	2.032131		
No. of tubers/plant	0.22	0.40 (ns)	0.05	0.152198422		
Plant tuber weight	0.27	0.62 (ns)	0.07	0.008912		
Starch content	0.69	7.33 *	0.48	0.682356*	5.591 (ns)	y = + 0.682 x
Harvest Index	0.45	2.06 (ns)	0.20	0.045377678		

* P < 0.05; ** P < 0.01; ns = not significant.

Table 11: Paired regressions between Dry Matter Content (X) and other traits (Y) of the potato entries under normal irrigation conditions

Variables	Correlation Index (XY)	Fisher's test	R^2	Slope	Intercept	Equation of a regression
Plant height	0.42	1.74 (ns)	0.18	-3.11619		
Plant canopy (90 DAP)	0.06	0.03 (ns)	0.003	0.452123		
Tuber Yield	0.44	1.98 (ns)	0.19	1.701122		
Mean tuber weight	0.32	0.89 (ns)	0.10	4.710136		
No. of tubers/plant	---	0.0003 (ns)	---	-0.00501		
Plant tuber weight	0.44	1.94 (ns)	0.20	0.028876		
Starch content	0.86	22.9 **	0.74	0.911659**	- 4.5848 (ns)	y = + 0.912 x
Harvest Index	0.31	0.85 (ns)	0.09	0.018689904		

* P < 0.05; ** P < 0.01; ns = not significant.

Table 12: Paired regressions between parameters within each genotype under moderate water deficit conditions

Entries	Correlation Index	Fisher's test	R^2	Slope	Intercept	Equation of a regression
Paired regression between Dry Matter Content (X) and Plant Height (Y)						
388676.1	0.998	285 *	0.996	10.15278*	-141.579 (ns)	y = + 10.152 x
Paired regression between Dry Matter Content (X) and Plant Canopy (Y)						
388615.22	1.0	40646 **	1.0	7.461538**	105.499**	y = -105.499 + 7.461 x
Paired regression between Dry Matter Content (X) and Tuber Yield (Y)						
397035.26	1.0	12 988 **	1.0	-17.3158**	386.198**	y = 386.198 - 17.315 x
Paired regression between Dry Matter Content (X) and Tuber Weight Plant^{-1} (Y)						
391180.6	1.0	4275 **	0.99	-0.46462**	10.588**	y = 10.588 - 0.464 x

* P < 0.05; ** P < 0.01; ns = not significant.

CIP 388676.1 – dry matter and plant height	y= 10.152x;
CIP 388615.22 – dry matter and plant canopy	y= -105.499+7.461x;
CIP 397035.26 – dry matter and tuber yield	y= 386.198–17.315x;
CIP 391180.6 – dry matter and tuber weight plant^{-1}	y= 10.588–0.464x.

All the other paired regressions concerning the other genotypes not above considered were not significant ($P<0.01$ and <0.05).

Conclusions

In the present study the effects of drought on growth, yield and quality of different potato genotypes were evaluated under the arid and semi-arid lowland conditions of Central Asia. The climate is classified as sharply continental with extremes of temperature in winter and summer. Despite agro-climatic conditions that do not appear favorable to the crop, potatoes are grown with relative success and the cultivated area increases annually. To partially mitigate the effects of hot temperature during the months of July and August, farmers increase the frequency of irrigation by applying water every 5 to 7 days and plant seed tubers with orientation towards the south-east to keep soil moisture.

All measured parameters (plant height, plant canopy, tuber yield, mean tuber weight, tuber weight plant^{-1}, number of tubers plant^{-1}, dry matter and starch content) revealed different levels of sensitivity to water stress in the field. Among the genotypes tested, Sante together with CIP 397077.16 showed the highest HI meaning that they allocated relatively more carbon to the tubers under water stress than the other genotypes did. The correlation between DTI and HI under moderate water deficit demonstrates discrimination between less and more tolerant genotypes with CIP clones 397077.16 and 388615.22 appearing as the most tolerant ones under moderate water deficit.

To better compete with weeds and escape drought and heat situations, cultivars must combine greater stability with growth vigor and early or late maturing cycle depending on the time drought is expected. Clearly, further work is required both for quantifying the effects of environment on dry matter concentration and for determination of the extent to which stability of tuber dry matter concentration and of other traits differ between genotypes. We should also take into consideration that under water deficit conditions variability in soil texture and water-holding capacity could become an increasingly important source of variation that may mask genotypic differences. Finally, due to the relatively low water use efficiency of traditional furrow irrigation and its suitability only when water supply is abundant, research should be re-oriented towards its improvement through the Partial Root-zone Drying technique, for instance, or the application of other forms of irrigation that should be more suited to areas with water scarcity and with low water retention capacity soils.

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Effects of over-expressing of rice glycogenin-like protein (*OsGGT1*) on tolerance to complete submergence and drought stress

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Extended abstract

Glycogenin glucosyltransferases or glycogenins (GGTs) are members of glycosyltransferase family 8. In most organisms other than plants, GGT is involved in initiation of the biosynthesis of glycogen, an important energy storage carbohydrate. In higher plants genomes, proteins with similar sequences and conserved domains to glycogenins were found and some of these proteins have been shown to be upregulated by environmental stresses. In this study we have cloned the full sequence of the rice *OsGGT1* gene, and evaluated the effects of its overexpression on starch contents, and on the tolerance to complete submergence and drought stress. The transgenic plants were generated by *Agrobacterium*-mediated gene transfer of the rice cultivar 'Nipponbare'. Integration of the transgene was confirmed by genome PCR, while its expression was confirmed by northern and western blotting analyses.

Although the transgenic plants maintained significantly higher starch contents compared to 'wild type' plants, repressing *OsGGT1* expression did not result in complete depletion of the starch pool in the mutant line (*ggt*). After two days of complete submergence, the transgenic plants maintained significantly higher contents of starch compared to 'wild type' plants, whereas after four days the level of the starch was similar in both groups, which suggest that *OsGGT1* might be involved in protecting starch from the rapid depletion under submerged conditions. Under drought stress, the transgenic plants maintained significantly higher dry weight compared to 'wild type' plants. Our study suggests that plants glycogenin-like glucosyltransferases may play important role in the plant tolerance to abiotic stresses.

Genes involved in cross-tolerance to drought and salinity in *Leymus*: Identification and expression analysis in wheat-*Leymus* chromosome addition lines

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Extended abstract

Leymus mollis (Triticeae; Poaceae) is a useful genetic resource for wheat breeding via wide hybridization to introduce its chromosomes and integrate its useful traits into wheat. Although *L. mollis* is highly tolerant to drought and salinity, and resistant to various diseases, the genetic mechanisms controlling its physiological tolerance remain largely unexplored. We have differentially screened *Leymus* cDNA libraries and identified several genes found to be involved in cross-response and cross-tolerance to drought and salinity. Some of these genes were found to be upregulated not only under drought and salt stresses, but also under temperature-induced stresses and in response to plant phytohormones. Genes involved in the synthesis of jasmonic acid, an important stress signaling compound, were identified, including those for lipoxygenase and allene oxide cyclase (AOC). We also identified genes involved in the biosynthesis and metabolism of glycine betaine, a solute which protects cells from dehydration injury, such as those for phosphoethanolamine methyltransferase (PEAMT) and glycine decarboxylase.

The genome of *L. mollis* was found to have more copies of important genes such as AOC, PEAMT, auxin response factor (ARF) and chloroplast inositol phosphatase (CIP) compared to the genome of the cultivated wheat 'Norin 61' or 'Chinese Spring'.

The expression patterns of some representative genes were validated by northern blot and RT-PCR analyses in both *Leymus* and wheat *Leymus*-chromosome addition lines under different abiotic stresses. These genes represent a useful source of expressed sequence tags (ESTs) for the analysis and identification of *Leymus* chromosomes introduced into wheat. Furthermore, these ESTs provide significant tools for the development of EST-derived molecular markers for breeding wheat with cross-tolerance to drought and salinity stresses.

Over-expression of the rice monogalactosyldiacylglycerol synthase gene (OsMGD) enhances tolerance to multiple stresses in tobacco

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Extended abstract

The galactoglycerolipids, monogalactosyldiacylglycerol and digalactosyldiacylglycerol (MGDG and DGDG, respectively) are the predominant membrane lipids in green plant tissues, and they constitute ~75% of chloroplast lipids. In plants, MDGD biosynthesis is catalyzed by MGD synthase which transfers D-Gal from UDP-Gal to *sn*-1,2-diacylglycerol, and DGDG is synthesized by galactosylation of MGDG. Thus, MDG synthase is the key enzyme for the biosynthesis of galactolipids and, hence, construction of the plastid membranes. In the natural condition, plant growth is suffering various environmental stresses, and membranes in the plant cell become the major targets of these stresses. Regulation of membrane lipids property and composition are extremely important for plant to deal with such environmental stresses and make a considerable contribution for survival and adaptation.

In order to investigate the function of MGD synthase in enhancing plant survival and adaptation ability under stresses, we cloned a MGD synthase gene from rice (*OsMGD*), overexpressed it in tobacco, and investigated the responses of *OsMGD*-overexpressing plants under different stresses. Our result showed that the activity of MGDG synthase in transgenic tobacco was 2 to 4.5-fold than that of ‘wild type’, which indicated that the *OsMGD* is a functional MGDG synthase gene in rice. Under these stresses, the transgenic tobacco grew better than the ‘wild type’ tobacco, exhibited higher chlorophyll content, fresh weight and the ratio of root to shoot. Our results show that *OsMGD* plays an important role in coping mechanism for various stresses in plants. This also provides us a possible approach to enhance plant multiple stresses tolerance.

Cancelation of vernalization requirements and promotion of early flowering in wheat by chromosome addition from a wild relative, *Leymus racemosus*

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Abstract

The world's rapidly increasing population and the urgent need to increase food production necessitate the production of highly adapted and high-yielding wheat cultivars. Vernalization genes determine the winter versus spring growth habit in wheat and play a decisive role in its adaptation to a wide range of environments. Early flowering lets plants fill their grains before the onset of late-season drought or heat stress, which can cause considerable yield losses. Due to predicted global temperature increases in future early-flowering cultivars may increase yield and stabilize food production. Wild relatives of wheat have proven to be valuable source of new genes and desirable traits. This study describes the ability of added chromosomes from wheat wild relative *Leymus racemosus* to eliminate the vernalization requirement and promote early flowering. We evaluated wheat–*Leymus* chromosome introgression lines under field conditions in Sudan and Japan and under growth chamber conditions. In Sudan, two chromosome addition lines flowered four weeks earlier than their wheat background, 'Chinese Spring', whereas they were comparable to Chinese Spring in Japan. One substitution line flowered later than all tested genotypes in Sudan and Japan. Under long-day conditions in the growth chamber, the two addition lines and the substitution line flowered significantly earlier than Chinese Spring. Screening of allelic variations of vernalization and photoperiod genes indicated that Chinese Spring harbors only the dominants allele *Vrn-D1* whereas the three lines had the dominant allele *Vrn-D1*in addition to an insertion at the *Vrn-A1* 1ocus. No allelic variation at the other *Vrn* and *Ppd* loci was detected. The early flowering of the three lines is attributed to the presence of an insertion at the *Vrn-A1locus.* Identification of such allele for promoting a spring growth habit will contribute to breeding cultivars for specific environments and to developing spring populations that lack vernalization requirements.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely grown food crops in the world, and it grows under a wide range of environmental conditions. This wide adaptability is largely controlled by three groups of genetic factors (Kato and Yamagata 1988): vernalization genes, *Vrn*, which determine a plant's vernalization requirement, photoperiod genes, *Ppd*, which determine its photoperiod sensitivity, and genes that control earliness *per se*. These groups act together to determine flowering time and therefore define the genotype adaptability to particular environmental conditions and the resulting yield potential (Worland *et al.* 1998; Gororo *et al.* 2001).

The cloning of wheat vernalization genes (Yan *et al*. 2003, 2006) and the identification and characterization of alleles for spring and winter growth habits (Yan *et al.* 2004; Fu *et al.* 2005) have facilitated the development of gene-specific markers enabling the screening of large collections of wheat germplasm with allelic diversity in the *Vrn* genes.

Several reports described the *Vrn1* allelic composition of wheat germplasm and revealed its effects on grain yield potential under various environmental conditions (for example Iqbal *et al.* 2007). These reports clearly indicated the decisive role of the *Vrn-1* allelic composition in regional adaptation and agronomic performance of wheat genotypes. Owing to climate change and predicted increases in the global temperature, which may lead to short and worm growing season, early flowering may become advantageous for high yield and stable food production. Therefore, optimizing the *Vrn* allelic composition for specific production environments may offer possibilities for developing spring wheat cultivars with higher yield potential.

Breeders need diverse germplasm as donors of genes for disease resistance, adaptation to stresses and other useful traits. One tremendous source of these genes is the wild relatives of wheat, such as *Leymus* species. Several *Leymus* species have been hybridized successfully with wheat. Some of the resulting introgression lines possess potentially useful traits, including inhibition of biological nitrification (Subbarao *et al.* 2007), resistance to *Fusarium* head blight (Chen *et al*. 2005; Qi *et al*. 2008; Wang and Chen 2008) and salt tolerance (Liu *et al*. 2001). The importance of *Leymus* species in general and of *Leymus racemosus* in particular as a novel source for many economically important traits sparked our curiosity about the potential impact of *L. racemosus* chromosomes on wheat adaptation. In this paper, we describe the effect of added chromosomes from *L. racemosus* into the genetic background of bread wheat in eliminating the vernalization requirements and promoting early flowering under field conditions in Sudan and Japan, and under growth chamber conditions.

Materials and methods

Plant materials and phenotypic evaluation

Field experiments in Sudan were carried using eleven addition and two substitution wheat-*L. racemosus* lines in the genetic background of 'Chinese Spring' (CS) bread wheat, and four commercial wheat cultivars from Sudan ('Bohain', 'Imam', 'Tagana', and 'Khalifa', Table 1). The Sudanese cultivars were selected for their high adaptability to short and warm winter growing season. Field experiments in Japan were carried using the wheat-*L. racemosus* addition and substitution lines in addition to CS. Experiments were conducted at the Biotechnology and Biosafety Research Center experimental field (Shambat, Khartoum North, Sudan) in Sudan and at the Arid Land Research Center experimental filed in Japan (Tottori, west Japan). The experiments were executed using a randomized complete block design with three replications, and the number of days to flowering for each accession at each site was recorded. For simplicity, all accession names have been simplified by changing the prefix to TAC and shortening its serial number; for example, TACBOW0001 becomes TAC01.

On the basis of the results of this experiment, we selected addition lines TAC01 and TAC13 that showed, early flowering and a substitution line (TAC17, with delayed flowering) and evaluated them again in comparison with CS and with Bohain in a growth chamber under long-day (16 h) conditions (without vernalization) at 25°C during the day, 15°C during the night, and 60% relative humidity.

Table 1: List of the genotypes used in the study

Accession ID	Accession Name	Number of chromosomes
TACBOW0001	*Leymus racemosus* A addition	44
TACBOW0003	*Leymus racemosus* E addition	44
TACBOW0004	*Leymus racemosus* F addition	44
TACBOW0005	*Leymus racemosus* H addition	44
TACBOW0006	*Leymus racemosus* I addition	44
TACBOW0008	*Leymus racemosus* K addition	44
TACBOW0009	*Leymus racemosus* L addition	44
TACBOW0010	*Leymus racemosus* N addition	44
TACBOW0011	*Leymus racemosus* H substitution	42
TACBOW0013	*Leymus racemosus* 5Lr#1 addition	44
TACBOW0014	*Leymus racemosus* 7Lr#1 addition	44
TACBOW0015	*Leymus racemosus* 7Lr#1 addition	44
TACBOW0017	*Leymus racemosus* 2Lr#1 substitution	42
Chinese Spring		42
Bohain		42
Tagana		42
Khalifa		42
Imam		42

DNA extraction and molecular markers analysis

Genomic DNA was extracted from the leaves of 10 days old seedlings using the CTAB method. We used specific primer pairs to identify allelic variation at *Vrn-A1*, *Vrn-B1*, *Vrn-D1*, and *Vrn-B3* (Yan et al. 2004, 2006: Fu et al. 2005). To exclude the effect of differences in flowering time among the accessions due to their photoperiod genes, we used the primer pairs, Ag5del_F2, Ag5del_R1 and Ag5del_R2, and Ppd-D1_F1 and Ppd-D1_R1 (Bentley *et al.* 2011) to confirm the allelic composition at the *Ppd-A1* and *Ppd-D1* loci respectively. Amplified PCR fragments were separated in 2% agarose gel stained with Gel Green (Biotium, Hayward, CA, USA).

Statistical analyses

Analysis of variance (ANOVA) followed by Fisher's PLSD test at $P < 0.05$ significance were carried using version 5.0.1 of the StatView software (SAS Institute Inc., 1998).

Results

Flowering time

Under field conditions in Sudan (11 h day length), all introgression lines flowered earlier than CS by an average of 32-7 days, except TAC17, the latest flowering genotype, which was comparable to CS (Fig. 1A). TAC01 and TAC13 were the earliest-flowering lines; however, they flowered significantly later than the earliest-flowering Sudanese cultivar Bohain by 12 days, and at dates comparable to those of the other commercial cultivars. Interestingly, under field conditions in Japan (13 h day length), the accessions mostly did not differ significantly in their flowering time, with the exception of TAC17, which was again the latest-flowering genotype (Fig. 1B). TAC01 harbors homoeologous-group 2 chromosome of *L. racemosus*, whereas TAC13 harbors group 5 chromosome. TAC17, in contrast, has group 2 chromosome of *L. racemosus* in place of chromosome 2B of wheat.

We further compared TAC01, TAC13, and TAC17 with CS and Bohain in a growth chamber under long-day conditions (16 h) without vernalization. All three lines flowered significantly earlier than CS by an average of 34 days, but not significantly differently from Bohain (Fig 1C). TAC13 flowered earlier than the other lines and Bohain by 9 days.

Allelic composition at the *Vrn* and *Ppd* loci

Table 2 shows the allele combinations in the three introgression lines and CS. All lines were tested with the primers VRN1AF and VRN1-INT1R for the *Vrn-A1* promoter region. Chinese Spring showed a 734-bp fragment, whereas all three introgression lines showed PCR fragments larger than the expected 734-bp detected in CS. The 734-bp fragment detected in CS is a characteristic of the dominant *Vrn-A1c* allele or the recessive *vrn-A1* allele (Fig. 2A). To distinguish between these alleles, we tested all lines using the primer pair Intr1/A/F2 and Intr1/A/R3, and Intr1/C/F and Intr1/AB/R for the first intron of *Vrn-A1*. No PCR product was produced using the primer pair Intr1/C/F and Intr1/AB/R, whereas a 1068-bp fragment was produced in all lines using the primer pair Intr1/A/F2 and Intr1/A/R3, indicating that all the introgression lines lacked the large intron 1 deletion that defines the *Vrn-A1c* allele and that the 734-bp amplification product detected in CS is the recessive allele *vrn-A1c* (Fig. 2B).

Using the primer pair Intr1/B/F and Intr1/B/R3 for the dominant spring allele *Vrn-B1*, no PCR fragment was produced, whereas all the tested genotypes possessed a 1149-bp fragment using primers Intr1/B/F and Intr1/B/R4, indicating that these lines had the recessive allele *vrn-B1* (Fig. 2C).

Table 2: Allelic variation at the *Vrn-A1*, *Vrn-B1*, *Vrn-D1*, *Vrn-B3*, *Ppd-D1*, and *Ppd-A1* loci

Genotypes	Vrn-A1	Vrn-B1	Vrn-D1	Vrn-B3	Ppd-D1	Ppd-A1
Chinese Spring	R	R	D	R	Ps	Ps
TAC01	D	R	D	R	Ps	Ps
TAC13	D	R	D	R	Ps	Ps
TAC17	D	R	D	R	Ps	Ps

R, recessive allele; D, dominant allele; Ps, photoperiod sensitivity allele.

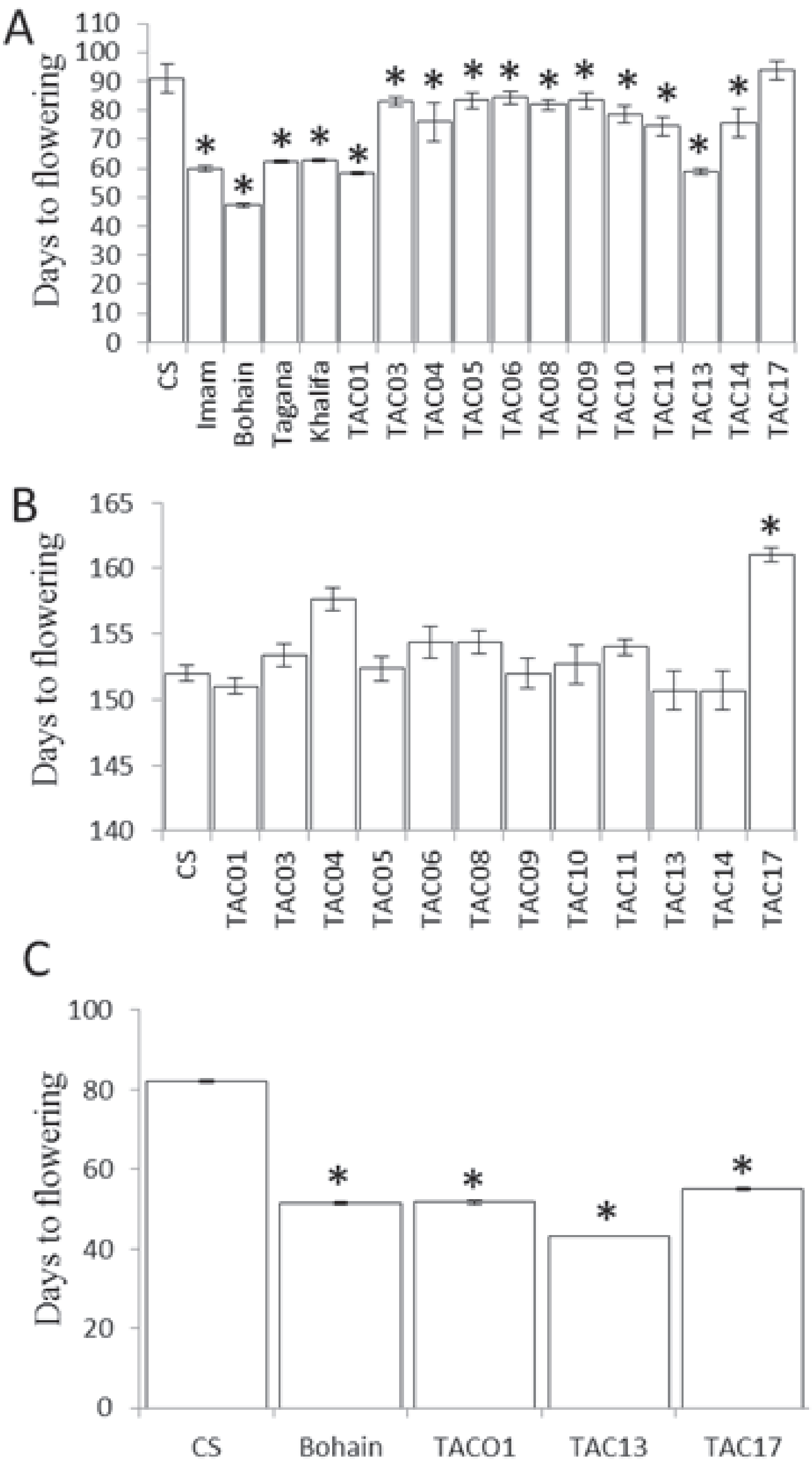

Figure 1: Days to flowering of 18 wheat and wheat–*Leymus racemosus* introgression lines and their wheat background Chinese Spring (CS) (A) in Sudan under field conditions (11 h day length), (B) in Japan under field conditions (13 h day length), and (C) under long-day conditions (16 h) in a growth chamber without vernalization. Data are means ± SE (n = 3). *Value differs significantly from Chinese Spring ($P < 0.05$, Fisher's PLSD test).

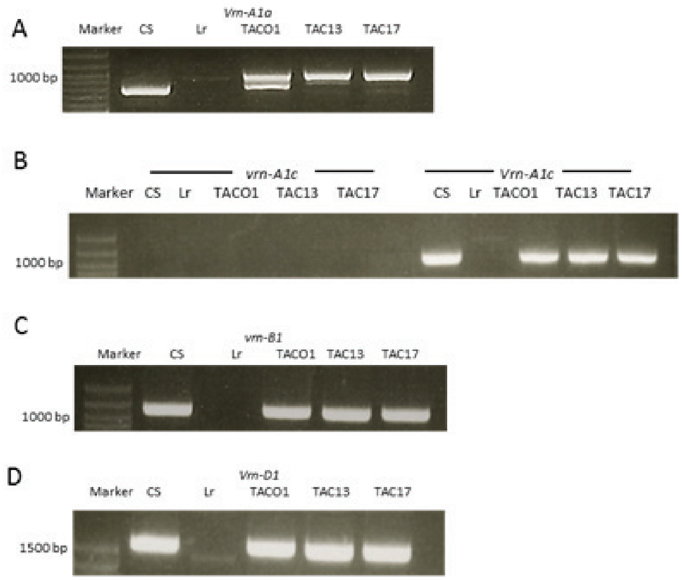

Figure 2: Polymerase chain reaction amplification to detect the allelic combinations of the *Vrn* genes using (A) primer pair VRN1AF and VRN1-INT1R for *Vrn-A1a*, (B) Intr1/C/F and Intr1/AB/R for *vrn-B1* and Intr1/A/F2 and Intr1/A/R3 for *Vrn-A1c*, (C) Intr1/B/F and Intr1/B/R4 for *vrn-B1*, and (D) Intr1/D/F and Intr1/D/R3 for *Vrn-D1*. Lr, *Leymus racemosus*.

A 1671-bp fragment, the characteristic of the dominant *Vrn-D1* was generated in all genotypes using the primer pair Intr1/D/F and Intr1/D/R3, and no PCR product was obtained using the primer pair Intr1/D/F and Intr1/D/R4. This result indicates that all the tested genotypes had the dominant allele *Vrn-D1* (Fig. 2D).

No allelic polymorphism was detected between the tested lines at the *Vrn-3*, *Ppd-A1* and *Ppd-D1* loci. In *L. racemosus*, no amplification was produced by using any of the primer sets suggesting that its vernalization and photoperiod genes are different from those of wheat.

Discussion

Our identification of the allelic composition of three key accessions using specific markers indicated that CS had the dominant allele *Vrn-D1* and the recessive alleles *vrn-A1* and *vrn-B1*. The introgression lines TAC01, TAC13, and TAC17 possessed *vrn-B1*, and *Vrn-D1* allelic combination in addition to about 950-bp product detected at the *Vrn-A1* loci. Yan *et al.* (2004) characterized the dominant *Vrn-A1a* allele and showed that it differs from the recessive allele by 222-bp insertion of a fold-back element in its promoter region. We used the same primer pair as used by Yan *et al.* (2004), and detected fragment larger than that of the recessive *vrn-A1*allel in the two addition and substitution lines.

We could not generate a PCR product from *L. racemosus* using the marker sets for the *Vrn* or *Ppd* alleles. Thus, the source of the insertion in the introgression lines remains unclear and should be clarified in future research.

The spring alleles of the *Vrn* genes are epistatic to the winter alleles (Pugsley 1971), and the winter growth habit is observed only when all genes have recessive alleles. The *Vrn-A1a* allele is the most potent allele for promoting a spring growth habit, and provides complete elimination of vernalization, whereas *Vrn-B1* and *Vrn-D1* only partially eliminate the requirement (Pugsley 1972). This confirms that CS has a vernalization requirement to promote flowering.

In Sudan, the wheat season is short and warm, especially in central Sudan (18°N to 22°N), whereas the wheat season in Japan is longer and colder. In Japan, wheat crops benefit from a long and cold winter, with heading occurring at the end of winter and the beginning of spring. In Sudan, winter wheat (which requires vernalization for ear emergence) is not grown on account of the warm temperatures, whereas winter wheat can grow in Japan and reach its maximum yield potential.

When the introgression lines were evaluated in Japan, all of them except TAC17 flowered at close to the same time as their background CS, but when they were evaluated in Sudan, TAC01 and TAC13 flowered significantly earlier and TAC17 flowered significantly later. In Japan, but not in Sudan, the wheat crop can achieve the vernalization requirement. Chinese Spring requires some vernalization to promote its flowering, as it only has the dominant allele *Vrn-D1*. This could explain the nearly flowering time in Japan and the late flowering of CS in Sudan where its vernalization requirement could not be achieved. On the other hand, the early flowering of TACO1, TAC13 in Sudan and in the growth chamber, and the early flowering of TAC17 in the growth chamber indicate that their vernalization requirement has been eliminated. The early flowering of TAC01 and TAC13 can be attributed to the effect of the insertion at the *Vrn-A1* locus. Same insertion was detected in TAC17, but this line showed delayed flowering in Sudan and Japan under field conditions and early flowering in the growth chamber under long-day conditions. This suggests the absence of the photoperiod-response *Ppd-B1* allele on chromosome 2B, which is replaced in TAC17 by chromosome 2Lr#1 of *L. racemosus.* However, we did not test for this substitution in our analysis.

In Sudan wheat growing season (winter) is very short ranging from 90 to 120 days; therefore, the late flowering cultivars usually suffer from the high temperature at the grain filling stage and a loss in productivity. Our study showed that CS with dominant allele *Vrn-D1* and *Ppd-B1* flowered in the range of 85 to 90 days, with onset of the high temperature and physiological maturity of the other genotypes. Thiss clearly indicates the importance of the allelic combinations of the vernalization and photoperiod genes in the adaptation and yield potential of wheat genotypes in heat-stress prone areas such as Sudan.

On the basis of these results, we conclude that the early flowering observed in the two addition lines and the substitution line resulted from elimination of the vernalization requirement by the presence of insertion at *Vrn-A1* locus, which might be *Vrn-A1a* or new allele. Identification of this allele will contribute to breeding cultivars for specific flowering environments and to the development of spring populations that lack a vernalization requirement. Molecular characterization of the insertion detected in this study may also explain the evolution of the *Vrn* spring alleles from the winter ones.

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Towards producing perennial wheat using wild species for breeding in arid land

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Abstract

Most cereal crops such as wheat and maize are annual. They grow from seeds, produce seeds for propagation in the next generation, and thus the life cycle is closed. This feature of annual plants necessitates soil tillage for sowing seeds in field, which has economic and environmental costs. If the plants were perennial, these problems could be avoided . Long and dense rhizosphere which is a feature of perennial plants must facilitate improvement of soil cohesion and water holding capacity and nutrient status in arid regions. *Leymus mollis* (2n=4x=28, NsNsXmXm), a wild species related to wheat, is perennial and distributed in the seaside. This plant has strong and long roots and is tolerant to salinity and heat. It grows vigorously and is propagated by producing robust rhizome. To transfer the useful features of *L. mollis* into wheat, we produced hybrids (n=5x=35) between *L. mollis* and wheat cultivar 'Norin 61' (2n=6x=42, AABBDD). The hybrids have perennial nature. The hybrids were backcrossed with Norin 61 and we obtained only one seed of BC_1F_1 generation. The BC_1F_1 plant was fertile, and thus the selfed seeds (BC_1F_2) could be produced. We found that some of the BC_1F_2 plants produced new tillers after harvesting seeds like perennial plants. We have been investigating the nature of the plants.

Introduction

Wheat (*Triticum aestivum*, 2n=6x=42, AABBDD) is one of three major cereal crops and a good source of protein for human consumption. Wheat is annual and thus vegetates from a seed and produces seeds for propagation in the next generation. Then it closes the life cycle. This feature necessitates a tilled soil for sowing seeds in field by annual tillage. The operation has economic cost and it creates soil environmental problem such as erosion. Occasional heavy rains cause soil erosion in arid land. In contrast, perennial plants do not require annual tillage. They develop long and dense root system (DeHaan *et al.* 2005), which must facilitate improvement of soil cohesion and water and nutrient status of the soil in arid regions.

Leymus mollis (2n=4x=28, NsNsXmXm), a wild species related to wheat, is perennial (Kishii *et al.* 2004). This plant has strong and long roots. It is distributed in seashore and is tolerant to salinity and drought (McGuire and Dvorak 1981). It grows vigorously and is propagated by producing robust rhizome. The purpose of this study was to produce wheat with perennial nature that must be useful in dry land and to improve its tolerance against heat and salinity using genes of *L. mollis*.

Materials and methods

To transfer the useful traits of *L. mollis* into wheat, common wheat cultivar 'Norin 61' was crossed as female with *L. mollis* as male. Twenty-four hours after pollination, 2, 4-D (50 mg/l) was applied and this was followed by embryo rescue to obtain hybrid plants (Kishii *et al.* 2004). Two F_1 hybrid plants were successfully obtained. The F_1 hybrids plants were backcrossed with

'Norin 61', and one BC_1F_1 plant was obtained. After self-fertilization, seeds in BC_1F_2 generation were obtained (Fig. 1).

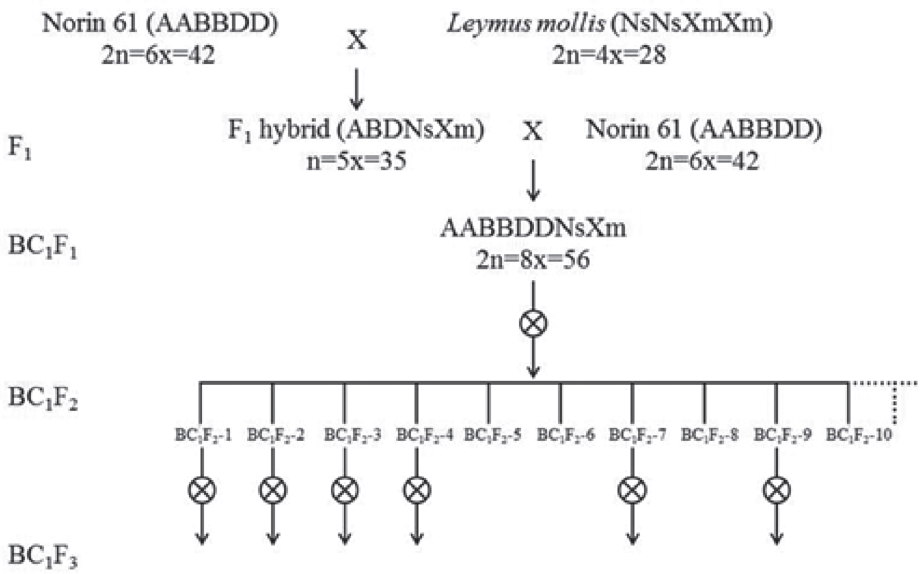

Figure 1: Pedigree of *L. mollis* chromosome addition lines.

The BC1F2 plants were used to observe morphology. After self-fertilization in several BC1F2 plants, seeds in BC1F3 generation were obtained. In chromosomal observation, root tips were pretreated on ice water for 24 hours and they were fixed in ethanol: acetic acid (3:1 v/v) fixative solution for at least 5 days at room temperature. The roots were squashed between glass slides and cover glassed and then frozen at -80 °C. After removal of the cover glass and then air-drying, the root tip cells on the slides were used to perform genomic in situ hybridization (GISH) to distinguish L. mollis chromosomes from 'Norin 61' chromosomes. Genomic DNA extracted from leaves of L. mollis by the CTAB method (Murray and Thompson 1980) was labeled by random-primer labeling method with tetramethyl-rhodamine-5-dUTP and used as the probe.

Result and discussion

After crossing between 'Norin 61' and *L. mollis*, F_1 hybrid plants were obtained by using embryo rescue. In the F_1 hybrid plants, 35 chromosomes were observed under a microscope. GISH revealed chromosome composition in the F_1 hybrid plants. The 14 chromosomes from *L. mollis* and the 21 chromosomes from 'Norin 61' were identified (Fig. 2a). The F_1 hybrid plants were backcrossed with 'Norin 61'. Finally, only one BC_1F_1 plant was obtained. In the BC_1F_1 plant, the number of chromosomes was 56. The 14 chromosomes of *L. mollis* were discriminated from 42 chromosomes of 'Norin 61' by using GISH (Fig. 2b).

In morphology, the F_1 hybrid plants showed vigorous growth (Fig. 3a). Also, new tillers, indicative of the perennial nature, appeared in the F_1 hybrid plants (Fig. 3b). In the BC_1F_1 plants, the phenotypic feature was similar to the F_1 hybrid plants.

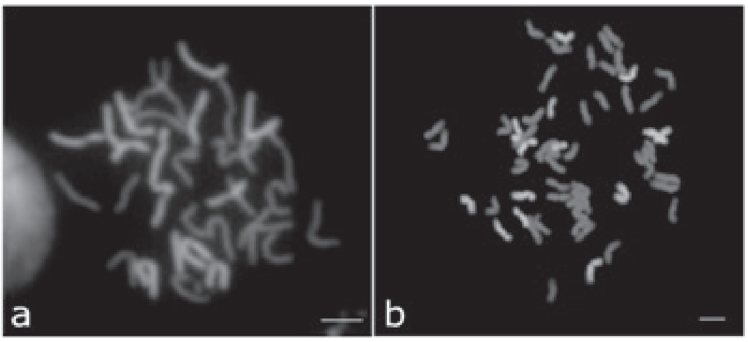

Figure 2: Karyotypes of (a) F_1 and (b) BC_1F_2 plants. *L. mollis* chromosomes are bright. 'Norin 61' chromosomes are dark. Scale bar, 10 µm.

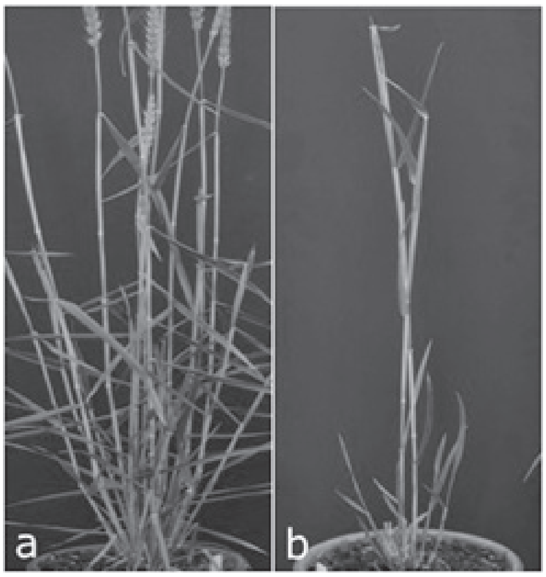

Figure 3: Phenotypes of F_1 plants. (a) Vigorous growth of F_1 plants and (b) perennial nature of F_1 plants.

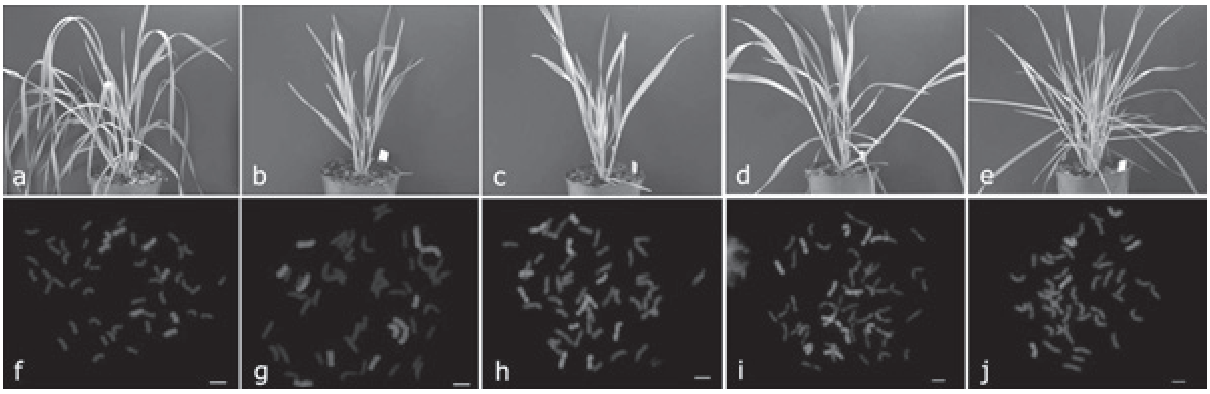

Figure 4 (a–e): Phenotypes and (f–j) karyotypes of BC_1F_2 plants. *L. mollis* chromosomes are bright. 'Norin 61' chromosomes are dark. Scale bars, 10 µm.

The BC_1F_1 plant was fertile but had low frequency of seed set. After self-fertilization, seeds in BC_1F_2 generation were obtained. The phenotypic characteristics and chromosomal composition in BC_1F_2 were examined (Fig. 4). For example, in phenotype of leaves, one plant had bended leaves (Fig. 4a), whereas the leaves of the other plants grew straight (Fig. 4a and 4b). One plant showed intermediate phenotype (Fig. 4d). One plant had stiff and slender leaves (Fig. 4e). In those plants, various chromosome compositions were shown by GISH (Fig. 4 f-j).

Some of the BC_1F_2 plants, after harvesting seeds, produced new tillers like perennial plants. The nature of the plants is being investigated. These lines, however, cannot be used directly for breeding because of genetic imbalance. If the plants with the perennial nature under genetic balance can be produced, it must be useful for improvement breeding for arid-lands.

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Chromosome elimination by super-wide hybridization between wheat or oat and pearl millet: CENH3 dynamics in the hybrid embryo cells

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Abstract

Sustainable production of food is threatened by global climate change, expansion of the world population and water resource shortage. Plant breeding for the sustainable food production is performed all over the world. In wheat breeding, germplasm enhancement and development of genes to combat climate change and water shortage is required. Pearl millet (family Poaceae, sub-family Panicoideae) is a drought and salinity tolerant crop, and thus, it is important in the Africa and Indian semi-arid regions. Wheat and oat (family Poaceae, sub-family Pooideae) are important crops for human and animals. However, they do not have a strong tolerance to drought and salinity. We intended to introduce the millet tolerant genes to wheat and oat plants by super-wide cross method. First we crossed wheat and oat with pearl millet and observed the dynamics of millet chromosomes in the hybrid embryo cells seven days after pollination using the fluorescence *in situ* hybridization (FISH) method and immunostaining method with CENH3 (centromere histone H3) antibody. In the cross between oat and pearl millet, all pearl millet chromosomes were retained, and CENH3 were located in the oat and pearl millet centromere. As a result, we could obtain true oat-pearl millet hybrids, but the hybrids showed sever necrosis. On the other hand, in the cross between wheat and pearl millet, the pearl millet chromosomes were gradually eliminated during embryogenesis. The eliminated chromosomes showed sever chromosome aberrations, such as breakage, chromosome bridge, non-disjunction and micronuclei formation. However, CENH3 were localized both on wheat and pearl millet centromere. These results indicated that the cause of the chromosome elimination in wheat-pearl millet hybrids was not simply explained as a malfunction of the kinetochore binding to the spindles. The wheat and oat plants with a pearl millet chromosome may be used as breeding materials in wheat improvement for harsh environmental condition.

Introduction

Current cereal production does not satisfy the global demand, and thus we are facing a global food crisis. A sustainable agricultural system must be developed in order to supply food to the expected population of 10 billion people in the mid-21st century, without damaging the environment. Plant genetics and breeding science can contribute to this goal by providing new genetic variation for cereals to increase their yields.

Wide hybridization is a promising method that can be used to expand genetic variation in common wheat (*Triticum aestivum*) by incorporating genetic material from other species. Many interspecific hybrids have been produced by wide crossing, and wheat lines possessing a specific chromosome arm or chromosome segment with a desired characteristic have been selected from the offspring of such crosses and adopted into breeding programs. However, during the initial step of interspecific hybridization, a variety of abnormalities, called “crossing barriers”, are often encountered. Barriers that occur before fertilization, such as the failure of pollen germination or of pollen tube elongation, are not common in the wide hybridization between wheat and its related species, whereas barriers that occur after fertilization are common. Single fertilization, in which one of the sperm cells fertilizes the egg cell, leaving the central cell unfertilized, results in seeds that lack endosperm, and appears frequently in interspecific hybridization. In this case, rescue and culture of the hybrid embryos can successfully result in adult hybrid plants. In the case of chromosome elimination, chromosomes from the male gamete are excluded from the nuclei during embryogenesis, and embryo rescue results in a wheat haploid line rather than a hybrid.

In Poaceae, chromosome elimination is often observed in various cross combinations (Houben *et al.* 2011). The molecular mechanisms that underlie the chromosome elimination seen in various cross-combinations remain to be solved. Several explanations have been proposed for this chromosome elimination. In wheat–maize crosses, the maize DNA was replicated and the first zygotic division exhibited sister chromatids, but the kinetochores of the maize chromosomes were not attached to the spindles (Mochida *et al.* 2004). In wheat–pearl millet (here after just millet) cross, the millet chromosomes are gradually eliminated during the 3 weeks after pollination. Millet chromosomes are eliminated by the mechanisms of nuclear extrusion and chromosome lagging (Gernand *et al.* 2005). In oat–maize crosses, several maize chromosomes are retained, and oat–maize chromosome-addition lines are generated (Kynast *et al.* 2001). In barley (*Hordeum vulgare*)–*H. bulbosum* crosses, failure of the recruitment of CENH3 to the centromeres is the cause of chromosome elimination (Sanei *et al.* 2011). CENH3 is one of the key factors involved in chromosome elimination.

If the elimination mechanism can be elucidated and controlled, it will be possible to take advantage of the genetic resources of maize, millet, and other distantly related species for wheat breeding, and novel wheat cultivars with the characteristics of maize or millet could be produced.

In this study, we used millet pollen to pollinate species of the tribe Triticeae with a variety of genome constitutions and oat, with the goal of observing the behavior of the millet chromosomes during hybrid embryogenesis by means of molecular cytogenetics, fluorescence *in situ* hybridization (FISH), and immunostaining using a CENH3 antibody common to the Poaceae (grassCENH3; Nagaki *et al.* 2004).

Materials and methods

Plant materials

We used Triticeae with various genome constitutions as female (AABBDD, AABB, AABBEE, AABBNN, AABBUU, AABBS^sS^s, AAGGDD, AABBRR, AABBDDRR, AA, RR, VV, HH) and oat. Pearl millet (*Pennisetum glaucum*; 2n = 2x = 14) cv. Ugandi was used as the male.

Chromosome observation in hybrid cells

Florets were fixed 7 days after pollination, and the embryos were excised and observed dynamics of the millet chromosomes by fluorescence *in situ* hybridization (FISH) probed with the genomic DNA of the millet and its centromere-specific repetitive sequences. We detected CENH3 using the antibody grassCENH3 (Nagaki *et al.* 2004).

Results and discussion

Elimination of millet chromosomes during embryogenesis

In oat-millet cross, chromosome elimination was not observed (Fig. 1a-c), whereas, other crosses exhibited various types of rearrangements in the millet chromosomes and its micronuclei (Fig. 1d-f). Normal millet chromosomes are metacentric or submetacentric. But in hybrid embryo cells, many millet chromosomes were heterobrachial, and some consisted of only the centromere and pericentric regions (Fig. 1g-i). Chromosome breakage appeared most frequently.

These rearranged chromosomes and micronuclei formed through breakage of chromosome bridges, leading to translocation of the millet chromosomes or retention of only their centromeric regions during anaphase. In addition, we observed non-disjunction of the millet chromosomes. In contrast, in the cross with oat, we observed no rearrangements of the millet chromosomes. Millet chromosomes in these cells behaved like the oat chromosomes.

Embryo culture of oat–millet hybrids

In oat–millet crosses, millet chromosomes were not eliminated during embryogenesis. Thus, we allowed the seeds to develop for 14 days after pollination and then transferred the embryo onto rescue medium (Fig. 2). Twenty hybrid embryos showed abnormal growth and died finally by necrosis (Fig. 2d-f). These plants were found to carry a full set of pearl millet genome (Fig. 2k). One embryo grew up to adult, but it was smaller than normal plants (left plant of Fig. 2g). This plant was haploid carrying only 21 chromosomes (Fig. 2h). Callus appeared from one of the embryos (Fig. 2i). This callus grew vigorously even in hormone free medium but did not regenerate. FISH revealed presence of only four of seven pearl millet chromosomes in this callus (Fig.. 2l). True hybrid may exhibit genetical imbalance, which may cause death, but it may be avoided by elimination of three of the millet chromosomes, causing vigorous callus cells. However, remaining chromosomes may suppress regeneration to plant. Endosperm was associated with some of the hybrid embryos. Chromosome aberration was observed in the endosperm (Fig. 2j, closed arrowheads) including oat-millet translocation (open arrowheads).

We found stable millet chromosomes in the embryos, seedlings, and callus of the hybrids with oat. This is in contrast with the case for crosses of oat with maize, in which maize chromosomes become unstable and are eliminated; as a result, oat–maize chromosome addition lines were generated (Kynast *et al.* 2001). The seedlings of true hybrids between oat and millet showed severe necrosis and died. One exceptional haploid plant appeared in the same cross, but lacked all the millet chromosomes and had no genome conflicts; it was therefore able to grow into adult haploid plant. Thus, it appears that partial chromosome elimination during embryogenesis is required for the introduction of millet genes into oat.

Dynamics of CENH3 during chromosome elimination

In the wheat–millet cross, few millet chromosomes were retained in the hybrid embryo cells on 7 days after pollination. Thus, we examined the dynamics of CENH3 in the embryo cells at 7 days after pollination using the grassCENH3 antibody. The wheat and millet centromere regions exhibited grassCENH3 signals (Fig. 3a, b). However, the centromeres in the micronuclei produced by elimination of the millet chromosomes did not have grassCENH3 signals (Fig. 3b).

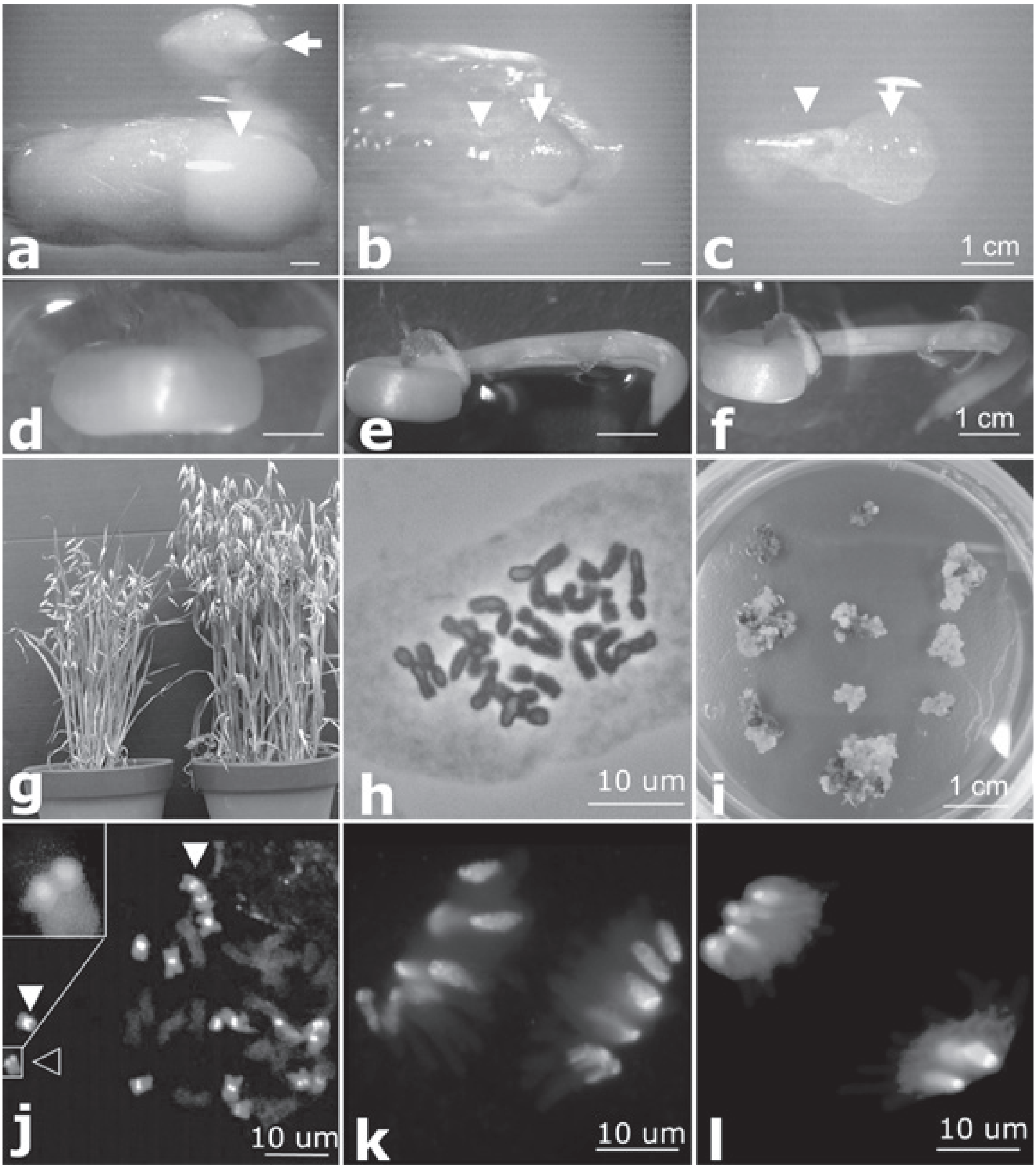

Figure 1: Behavior of millet chromosomes in hybrid embryos 7 days after pollination**.** (a-c) Oat–millet hybrid embryo cells: Cells at (a) interphase, (b) prometaphase, and (c) anaphase. (d-i) Triticeae–millet hybrid embryo cells. (d, e) Anaphase cells showing non-disjunct millet chromosomes (arrows), acentric fragments (hollow arrowheads), and small centromeric signals (closed arrowheads). (f) Elimination of the millet chromosomes results in the formation of micronuclei with one or more centromeres (closed arrowheads) or without a centromere (hollow arrowheads). (g-h) Small chromosomes consisting only of centromeric regions (arrows).

We analyzed the localization of grassCENH3 in the oat and millet chromosomes in the hybrid embryos on 7 days after pollination. The grassCENH3 signals were detected in both the oat and millet centromere regions (Fig. 3c, d).

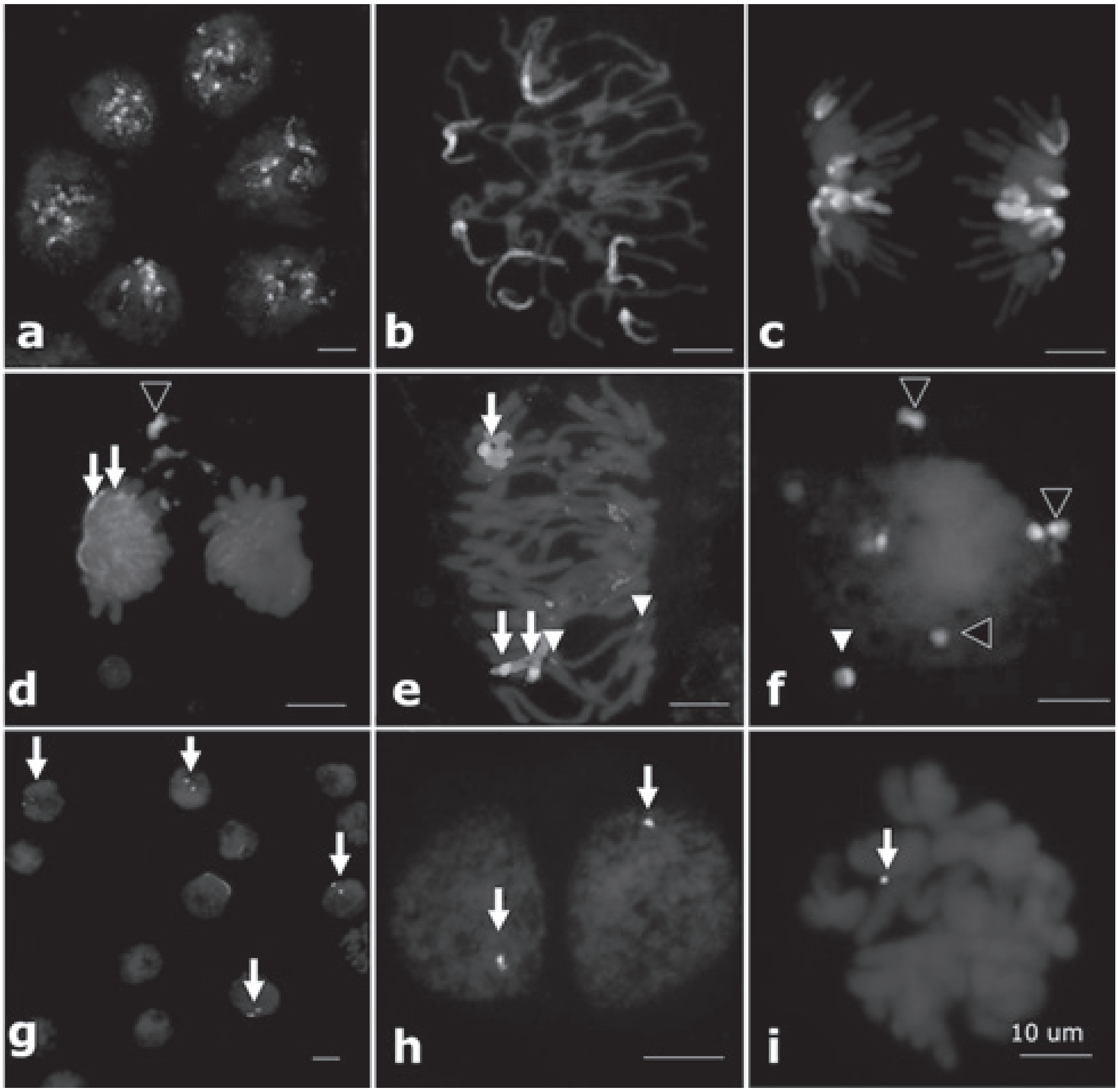

Figure 2: Culture of oat–millet hybrid embryos and cytological analysis of the endosperm and of callus cells. (a) A normal immature oat seed 14 days after self-pollination. (b) An immature seed 14 days after crossing between oat and millet. (c) An embryo excised from an immature hybrid seed: arrow, the embryo; arrowhead, the endosperm. (d-f) The embryo of the same oat–millet hybrids of different development stages. (g) Plants regenerated from an embryo (left) and wild-type oat plant (right). (h) Chromosomes of the regenerated plant (haploid). (i) The hybrid callus. (j) Oat–millet hybrid endosperm. Translocated chromosomes are pairs of oat and millet chromosomes (hollow arrowhead) or of millet and millet chromosomes (closed arrowheads). (k) Necrotic seedling plant chromosomes in the anaphase cell. (l) Hybrid callus chromosomes in the anaphase cell.

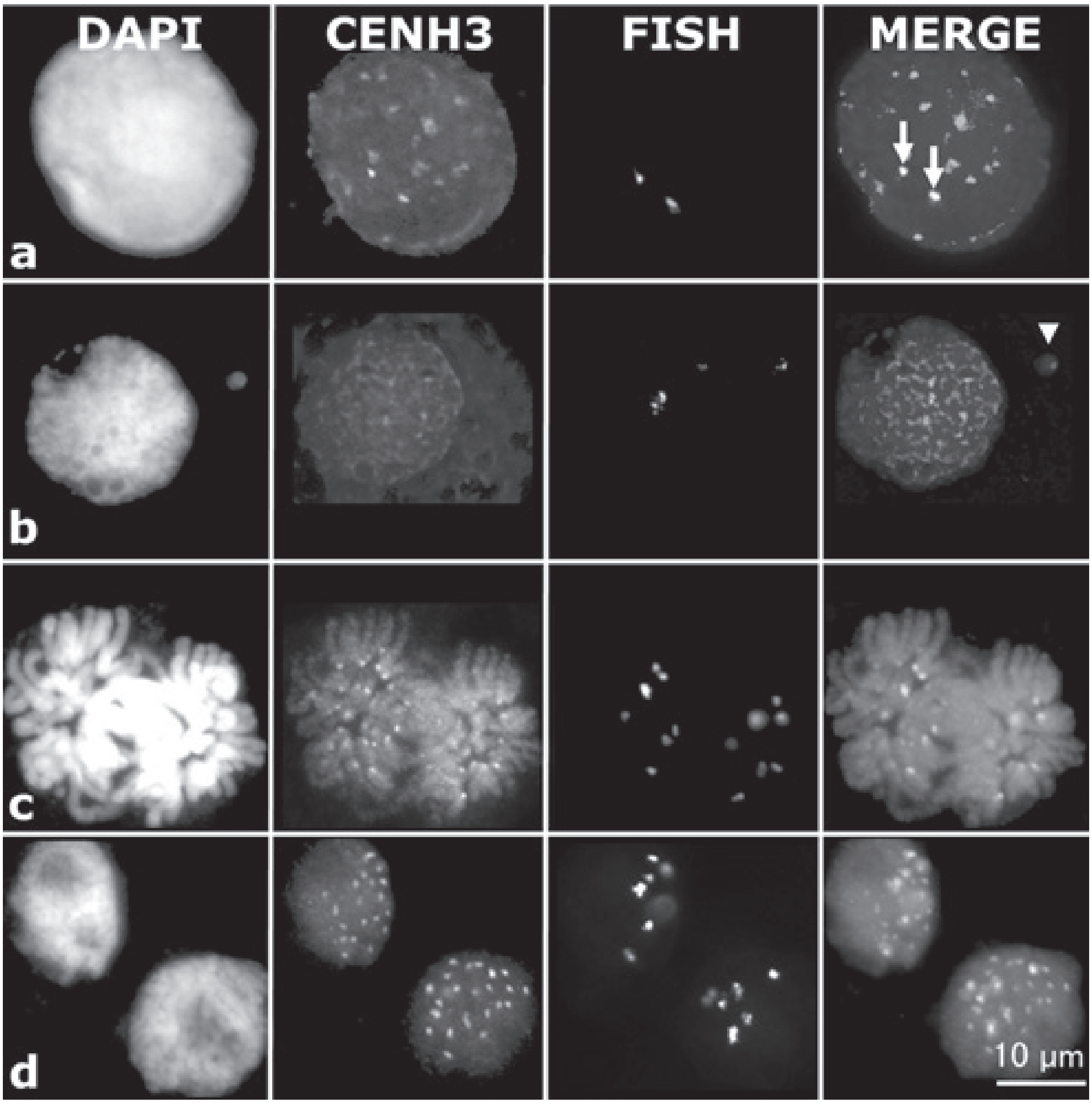

Figure 3: Localization of grassCENH3 in the wheat–millet and oat–millet hybrid embryo cells 7 days after pollination. (a) CENH3 was located in the wheat and millet centromeres in the nuclei (arrow). (b) CENH3 was not located in the millet centromere of the micronuclei (arrowhead). (c, d) CENH3 was located in the oat and millet centromeres. DAPI, DNA staining with DAPI; CENH3, anti-grassCENH3 signal; FISH, millet centromere DNA; MERGE, merged image containing all three signals.

These results indicated that the cause of the chromosome elimination in wheat–millet hybrids could not be simply explained as a malfunction of the kinetochore binding to the spindles.

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Growth responses and inorganic ion regulation of four bermudagrass (*Cynodon* spp.) cultivars under salinity stress

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Abstract

The need for salinity-tolerant turfgrasses is increasing owing to increased use of reclaimed or saline water for irrigation. The objective of this study was to investigate the salinity tolerance, growth, and physiological responses of four bermudagrass (*Cynodon* spp.) cultivars. The salinity treatments were 0, 100, 200, 300, and 400 mmol L^{-1} NaCl. The reduction in relative shoot growth with increasing salinity in the tested cultivars indicated a salinity tolerance in the order of 'Riviera' > 'Blackjack' > 'Savannah' > 'Sundevil 2'. Shoot growth, root growth, and relative water content of shoots and roots of all cultivars were significantly affected by NaCl stress. However, root length and root dry weight of the salt-tolerant cultivars Riviera and Blackjack increased significantly compared with the control. Tissue Na^+ and Cl^- concentrations in all cultivars increased with increasing salinity. Riviera accumulated less Na^+ and Cl^-in leaves and roots and more K^+ in leaves than the least tolerant cultivar, Sundevil 2. All cultivars had bicellular salt glands on both the abaxial and adaxial leaf surfaces. Riviera excreted more Na^+ and Cl^- than the other cultivars through saltglands. All grasses exhibited complete osmotic adjustment, and osmotic adjustment of Riviera was less than other cultivars under salinity stress. Our results indicate that the salinity tolerance of Bermuda grasses is associated with leaf and root Na^+ and Cl^- regulation, in conjunction with the maintenance of high leaf K^+ levels and efficient excretion of Na^+ and Cl^- by leaf salt glands.

Introduction

Rapidly increasing populations and urbanization, especially in arid and semiarid regions, are creating freshwater shortages. The United Nations predicts that 2.7 billion people will face severe water shortages by 2025 if water consumption continues at current rates (Montaigne 2002). Along with the increase in population, the volume of wastewater will also increase. The reuse of treated wastewater for irrigation of turfgrasses and landscapes is viewed as one way to use urban water resources more efficiently. Many American states have responded by passing laws to limit the use of potable water for landscape and turfgrass irrigation, and to require the use of recycled or saline secondary water sources for irrigation (Qianand Harivandi 2008; Marcum 1999). Approximately 260 golf courses across America now use recycled water for irrigation (Qianand Harivandi 2008). For these reasons, the need for salt-tolerant turfgrass cultivars has substantially increased in recent decades.

Bermudagrass (*Cynodon* spp.), the most popular turfgrasses in warm regions worldwide, is well-adapted to a wide range of soil conditions, being tolerant of drought and a broad salinity range (Carrow 1996; Marcum and Pessarakli 2006). Although a number of studies have compared the salinity tolerances of several *Cynodon* cultivars (Dudeck and Peacock 1993; Dudeck *et al.* 1983; Francois 1988; Marcum and Pessarakli 2006; Peacock *et al.* 2004; Smith *et al.* 1993), few have attempted to elucidate the mechanisms of salt tolerance.

Bermudagrass cultivars exhibit a wide range of salinity tolerance. Salinity tolerance (according to the salinity level that causes 50% shoot growth reduction) ranged between 26 and 40 dS m^{-1} among 35 *Cynodon* spp. cultivars (Marcum and Pessarakli 2006). Cultivars within a given species that exhibit superior salinity tolerance must possess different physiological mechanisms from the least tolerant types. Understanding the salinity tolerance mechanisms of the most tolerant cultivars will not only accelerate the breeding of new cultivars, but also will assist in stabilizing saline soils through the use of salt-tolerant turfgrass.

The adverse effects of salinity on plant growth are typically caused by ionic imbalance, hyperosmotic stress, or both (Zhu 2001). Saline ion exclusion by shoots has been associated with salinity tolerance across both C_3 and C_4 turfgrass species (Marcum 1999; Qian *et al.* 2001). Turfgrasses may exclude saline ions in several ways: via an accumulation of compatible solutes associated with ion compartmentation, exclusion at the root cortex, and excretion by salt glands (Marcum and Pessarakli 2006). Bermudagrass has salt glands on both the abaxial and adaxial leaf surfaces (Marcum 1999), and the degree of salinity tolerance among various bermudagrass cultivars was positively correlated with the Na^+ excretion rate by the salt glands and negatively correlated with the leaf tissue Na^+ concentration (Marcum and Pessarakli 2006). These results indicate that the salinity tolerance mechanism in bermudagrass is associated with both Na^+ exclusion and Na^+ excretion. However, Na^+ and Cl^- play important roles in osmotic adjustment. Saline ion regulation, rather than exclusion, may therefore be a more apt description of the salinity tolerance mechanism in turfgrasses (Marcum 2008). However, the Cl^- concentration in leaves, the ionic concentrations in roots, and the characteristics of the ionic distribution between leaves and roots of various bermudagrass cultivars have not yet been reported.

The objectives of present study were to determine the salinity tolerance, growth, and physiological responses of four bermudagrass cultivars with different salinity tolerances.

Materials and methods

Plant materials and growth conditions

We used four bermudagrass cultivars (‘Riviera’, ‘Sundevil 2’, ‘Savannah’, and ‘Blackjack’) in this study. Experiments were conducted from April to July 2009 at the Faculty of Agriculture, Tottori University. Seeds were sown in plastic containers filled with vermiculite, and the seedlings were grown in a glasshouse under natural light. One-month-old seedlings were transferred into 4-L plastic pots, four to a pot, at the two-leaf stage. The pots contained half-strength, constantly aerated Hoagland’s No. 2 solution (Hoagland andArnon 1950), modified by the addition of Fe-EDTA to supply 3 mg L^{-1} of Fe. Solutions were renewed weekly throughout the experiment. Grasses were grown for 4 weeks in nutrient solution to allow them to become densely established before we initiated the salinity treatments.

Salinity treatment and data collection

Five salinity levels of 0 (control), 100, 200, 300, and 400 mmol L^{-1} were prepared by dissolving NaCl in nutrient solution. The hydroponic system comprised of 20 (five salinity levels and four replications) pots for each cultivar. To avoid osmotic shock, salinity was gradually increased by

50 mmol L^{-1} per day until a final salinity level of 400 mmol L^{-1} NaCl was reached. Afterwards, plants in each treatment were grown for 35 days. Shoots and roots were clipped 1 day before the initiation of salinity treatments. Roots were clipped at a length of 15 cm to provide a common baseline for subsequent measurements. Data collection began at this point.

Shoot clippings were collected weekly for a total of three harvests during the experiment. After the fresh weight (FW) was recorded, the clippings were immediately oven-dried at 70 °C for 72 h, then the dry weight (DW) was recorded. Three harvests were combined to produce a single total shoot FW and DW. Root length, FW and DW of root were measured at the end of 35 d of salinity treatment. We calculated the relative water content (RWC) of shoots and roots as:

RWC (%) = [(FW – DW)/FW]´100%.

Leaf and root ion concentrations (Na^+, K^+, and Cl^-)

At the end of experiment, leaves were thoroughly rinsed with deionized water to remove external salts, and then allowed to air-dry before being clipped. Roots were separated from the shoots and also rinsed with deionized water. Clipped leaves and roots were dried at 70 °C for 48 h, and the samples were ground in a blender before the ionic analyses. Concentrations of Na^+ and K^+ were measured by atomic absorption spectrophotometry (Polarization Zeeman Z-6100; Hitachi, Ibaraki, Japan). The Cl^- concentration was then measured by ion chromatography (CDD-10A SP, HIC-10A Super; Shimadzu, Kyoto, Japan).

Determination of osmotic potential

The osmolality of the collected sap from leaf and root was analyzed using a vapor pressure osmometer (Osmometer 5520; Wescor, Logan, UT, US). The osmotic potential was calculated using the van't Hoff equation (Nobel 1991; $\Psi_s = -cRT$), where c is the osmolality (mmol kg^{-1}), R is the gas constant, and T is the temperature (K).

Rates of ion (Na^+ and Cl^-) excretion by salt glands

Rates of ion excretion by salt glands were determined according to the method of Marcum (1999). Ion excretion rates are expressed as mg g^{-1} leaf dry weight per week.

Salt gland determination

The presence of salt glands in the leaves was determined according to the method of Alshammary *et al.* (2004).

Results

Plant growth

Shoot FW and DW of all four cultivars decreased significantly with increasing salinity (Table 1). However, a difference between the cultivars in this response was apparent. In comparison to the control, the shoot DW at 400 mmol L−1 NaCl was reduced by 48.9% for Riviera, 60.1% for Blackjack, 71.4% for Savannah, and 79.0% for Sundevil 2. Quadratic decreases in relative shoot growth (as a percent of control) were observed with increasing salinity levels for all cultivars. The predicted salinity level causing 50% reduction of relative shoot growth was 400.4 mmol L^{-1} NaCl in Riviera, 369.6 mmol L^{-1} NaCl in Blackjack, 305.3 mmol L^{-1} NaCl in Savannah, and 279.6 mmol L^{-1} NaCl in Sundevil 2. According to the salinity level causing 50% shoot DW reduction, the ranking for salinity tolerance of four bermudagrass cultivars was: Riviera > Blackjack > Savannah > Sundevil 2.

Table 1: Effects of NaCl stress on the growth of the shoots and roots of four bermudagrass cultivars

Cultivar	**NaCl (mmol L^{-1})**	**Shoot FW (g)**	**Shoot DW (g)**	**Root FW (g)**	**Root DW (g)**	**Root length (cm)**	**Shoot RWC (%)**	**Root RWC (%)**
Riviera	0	14.1±1.7 a	1.48±0.13 a	1.39±0.06 b	0.24±0.01 b	37.7±1.5 b	89.1±0.9 a	82.70.2± a
	100	10.5±0.6 b	1.45±0.07 a	1.67±0.08 a	0.33±0.01 a	47.4±1.2 a	86.2±0.3 b	80.10.2± b
	200	6.5±0.3 c	1.28±0.04 a	1.65±0.05 a	0.36±0.01 a	46.5±1.0 a	80.2±0.3 c	78.00.2± c
	300	3.9±0.2 d	0.88±0.03 b	1.27±0.06 b	0.32±0.02 a	38.2±1.1 b	77.7±0.3 d	74.70.4± e
	400	3.2±0.2 d	0.75±0.04b	0.99±0.08 c	0.24±0.02 b	32.4±1.0 c	76.5±0.3 d	76.00.2± d
Blackjack	0	12.5±0.7 a	1.40±0.04 a	1.48±0.08 b	0.26±0.01 b	36.8±1.0 b	88.7±0.4 a	82.50.9± a
	100	9.5±0.4 b	1.32±0.06 a	1.79±0.07 a	0.36±0.01 a	44.6±1.2 a	86.1±0.3 b	80.10.6± b
	200	6.1±0.5 c	1.11±0.07 b	1.50±0.06 b	0.34±0.03 a	43.4±1.1 a	81.5±0.6 c	77.41.3± c
	300	3.7±0.2 d	0.78±0.04 c	1.11±0.03 c	0.29±0.01 a	34.2±0.9 b	79.0±0.3 d	73.70.3± d
	400	2.3±0.1 e	0.57±0.02 d	0.89±0.06 d	0.25±0.02 b	29.5±1.9 c	75.2±0.3 e	72.00.5±d
Savannah	0	12.8±1.0 a	1.49±0.09 a	1.44±0.07 b	0.25±0.01 b	39.3±0.9 b	88.1±0.3 a	82.50.9± a
	100	6.8±0.3 b	1.25±0.04 b	1.68±0.08 a	0.34±0.02 a	46.2±1.6 a	81.5±0.4 b	80.00.7± b
	200	4.3±0.3 c	1.04±0.06 c	1.47±0.08 b	0.33±0.01 a	39.4±1.5 b	75.5±0.3 c	77.31.3± c
	300	3.0±0.1 cd	0.75±0.03 d	0.85±0.02 c	0.22±0.01 b	32.4±1.0 c	74.9±0.4 c	73.80.3± d
	400	1.9±0.1 d	0.51±0.02 e	0.81±0.03 c	0.23±0.01 b	28.9±1.6 c	73.4±0.3 d	72.00.4±d
Sundevil 2	0	12.9±0.9 a	1.41±0.12 a	1.42±0.09 a	0.26±0.02 a	36.6±1.2 b	89.0±0.7 a	81.40.3± a
	100	6.9±0.3 b	1.26±0.05 a	1.04±0.11 b	0.29±0.01 a	39.8±0.6 a	81.7±0.4 b	71.32.2± b
	200	4.1±0.2 c	0.99±0.03 b	0.71±0.03 c	0.26±0.01 ab	34.6±1.2 b	75.6±0.3 c	63.80.8± c
	300	2.3±0.1 d	0.61±0.03 c	0.58±0.05 cd	0.22±0.02 bc	27.7±0.9 c	73.0±0.3 d	61.80.7± cd
	400	1.1±0.02 d	0.32±0.01 d	0.46±0.03 d	0.19±0.01 c	22.8±1.3 d	71.1±0.3 e	59.01.5± d
ANOVA (*F* values)								
NaCl		245.5***	163.70***	96.47***	38.74***	108.0***	862.8***	139.6***
Cultivar (C)		16.3***	14.95***	72.73***	16.21***	38.8***	135.0***	169.6***
C×NaCl		1.4^{ns}	1.24^{ns}	6.99***	3.35***	2.9**	10.9***	10.5***

* *P*<0.05, ** *P*<0.01,*** *P*<0.001, ns, not significant. Values of a parameter for each cultivar followed by the same letter are not significantly different (*P*=0.05) according to Duncan's multiple-range test. Data are mean ± SE (n=6).

Root growth response differed from shoot growth. All four cultivars showed an initial increase in root length and root DW with increasing salinity, followed by a decrease to approximately the same level as in the control at the highest salinity levels (Table 1).Compared with the control, the root lengths of Riviera and Blackjack increased significantly at 100 and 200 mmol L^{-1} NaCl. However, those of Savannah and Sundevil 2 increased significantly only at 100 mmol L^{-1} NaCl, and then decreased significantly below the control level with increasing salinity. The root FW of Riviera, Blackjack, and Savannah increased significantly at 100 mmol L^{-1} NaCl, and that of Riviera also increased significantly at 200 mmol L^{-1} NaCl, and then decreased at higher salinity. However, the root FW of Sundevil 2 decreased significantly at all levels of increased salinity and continued to decrease. The root DW of Riviera and Blackjack was significantly larger than that of the control at 100, 200, and 300 mmol L^{-1} NaCl and did not differ significantly from that of the control at 400 mmol L^{-1} NaCl (Table 1). However, the root DW of Savannah increased significantly compared with that of the control at 100 and 200 mmol L^{-1} NaCl, and then declined significantly to a level comparable to that in the control. Sundevil 2produced its maximum root DW at 100 mmol L^{-1} NaCl, but this value did not differ significantly from the control. At 400 mmol L^{-1} NaCl, the root DW of Savannah and Sundevil 2 decreased by 14.1% and 28.8%compared with the control, respectively.

The RWC of the shoots and roots decreased significantly with increasing salinity in all four cultivars (Table 1). Riviera and Blackjack had significantly higher water contents in the shoots and Riviera had significantly higher water contents in the roots than the other turfgrasses at all salinity levels. Sundevil 2 had the lowest water contents among the cultivars at all salinity levels. In all cultivars, water content in the shoots was higher than in roots, except in Savannah at 200 mmol L^{-1} NaCl.

Na^+ concentration

The concentrations of Na^+ in the leaves and roots increased significantly with increasing salinity in all cultivars (Fig. 1). In the leaves, the difference among the cultivars in the response to salinity was particularly significant, especially at 300 and 400 mmol L^{-1} NaCl. At each salinity level, the most salt-tolerant cultivar, Riviera, had the lowest Na^+ concentration, and the most salt-sensitive cultivar, Sundevil 2, had the highest Na^+ concentration. Blackjack and Savannah had intermediate Na^+ concentrations at all levels. The most dramatic differences in Na^+ concentration among the cultivars were at 300 and 400 mmol L^{-1} NaCl. The Na^+ concentrations in Blackjack, Savannah, and Sundevil 2 were respectively 24%, 60%, and 122% higher than in Riviera at 300 mmol L^{-1} NaCl, and were 24%, 40%, and 107% higher at 400 mmol L^{-1} NaCl.

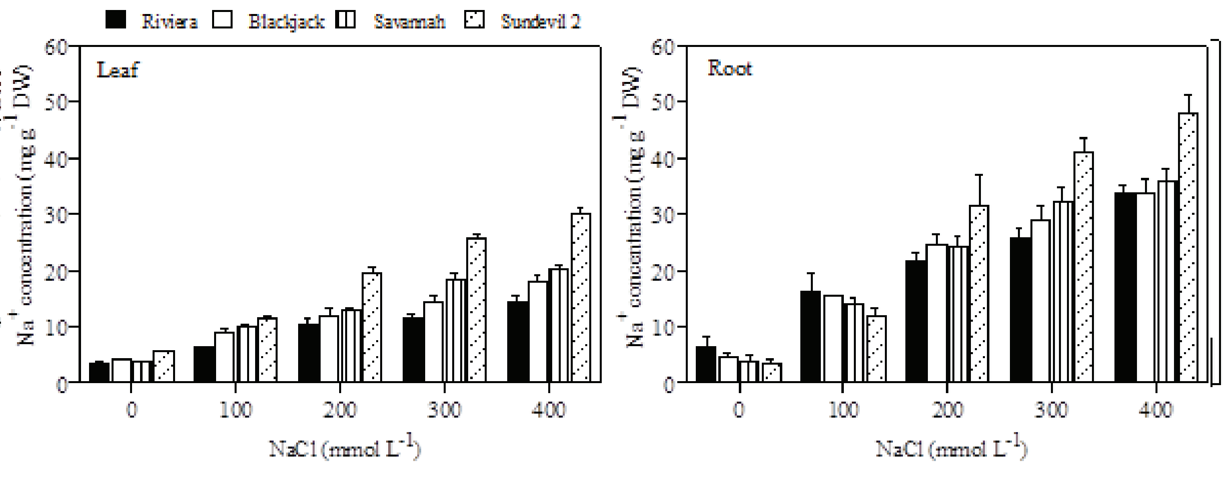

Figure 1: Na^+ concentrations in the leaves and roots of the four bermudagrass cultivars at 0, 100, 200, 300, and 400 mmol L^{-1} NaCl. Data are the means ± standard error (n = 4).

In the roots, there was no large difference in Na^+ concentrations among Riviera, Blackjack, and Savannah except at 300 mmol L^{-1} NaCl. Sundevil 2 had the highest Na^+ concentration at 200 mmol L^{-1} NaCl or higher. The Na^+concentrations in the roots of Sundevil 2 were respectively 45%, 60%, and 43%, higher than those of Riviera at 200, 300, and 400 mmol L^{-1} NaCl.

K^+ concentration

The concentration of K^+ in the leaves and roots of allcultivars decreased significantly as the NaCl concentration increased (Fig. 2). In the leaves, the K^+ concentration of Riviera was higher than that of Sundevil 2 at each level of NaCl. However, there was no significant difference in K^+ concentrations among Riviera, Blackjack, and Savannah, except at 100 mmol L^{-1} NaCl. In the roots, the K^+concentrations of Riviera and Blackjack were higher than those of Savannah and Sundevil 2, and the K^+ concentrations in each cultivar did not change significantly between 100 and 400 mmol L^{-1} NaCl. For all cultivars, K^+ concentrations in the leaves were higher than those in the roots at the same salinity levels.

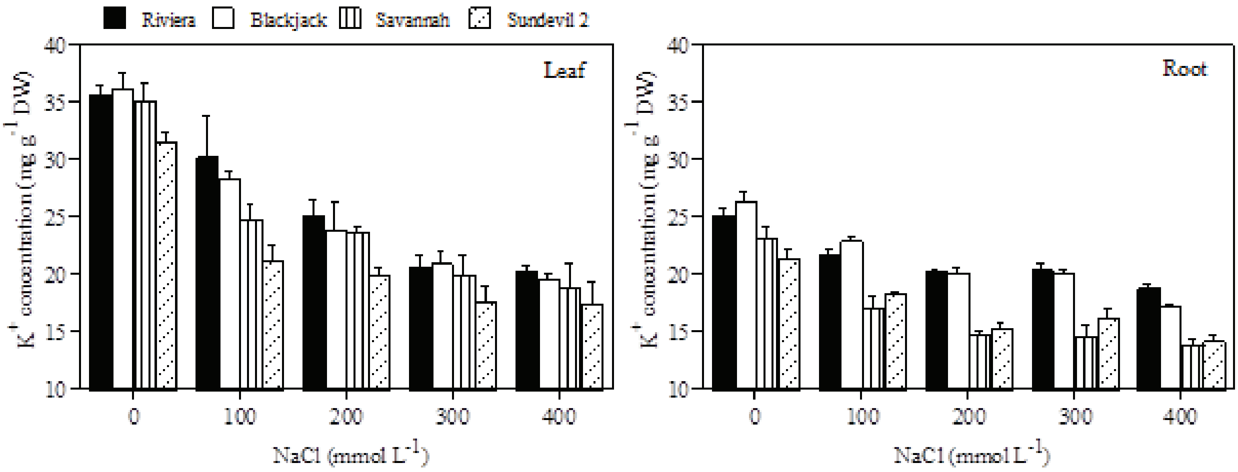

Figure 2: K^+ concentrations in the leaves and roots of the four bermudagrass cultivars at 0, 100, 200, 300, and 400 mmol L^{-1} NaCl. Data are the means ± standard error (n = 4).

Cl^- concentration

The Cl^-concentration in the leaves and roots of four cultivars also increased with increasing salinity (Fig. 3). In general, the leaves and roots of Riviera had significantly lower concentration than those of the other three cultivars, except at 0 and 100 mmol L^{-1} NaCl. The concentration in the leaves and roots of Blackjack, Savannah, and Sundevil 2 did not change significantly at 200 and 300 mmol L^{-1} NaCl. However, in the leaves and roots of Blackjack the concentrations were lower than those in Savannah and Sundevil 2 at 400 mmol L^{-1} NaCl.

Relationships between osmotic potential and ionic concentration

The osmotic potential (Ψ_s) became more negative in both leaves and roots of all four cultivars as salinity increased. The measured Ψ_s averaged –1.62, –1.75, –1.85, and –2.04 MPa in the leaves of Riviera, Blackjack, Savannah, and Sundevil 2, respectively, under salinity stress. The measured Ψ_s averaged –1.36, –1.23, –1.30, and –1.26 MPa, respectively, in the roots. The Ψ_s in the plant tissues was lower than that of the growing media (an average of –0.93 MPa) in all cultivars. Na^+ and Cl^- concentrations in the leaves and roots were strongly ($R \geq 0.77$) correlated with the measured Ψ_s (Fig.4), indicating that Na^+ and Cl^- are important factors involved in osmotic adjustment in all four cultivars.

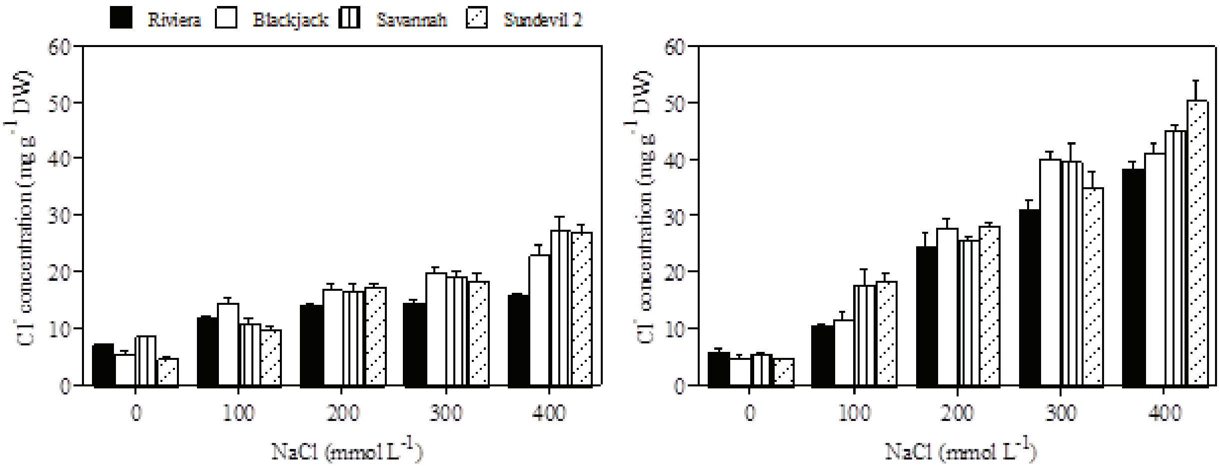

Figure 3: Cl^- concentrations in the leaves and roots of the four bermudagrass cultivars at 0, 100, 200, 300, and 400 mmol L^{-1} NaCl. Data are the means ± standard error (n = 4).

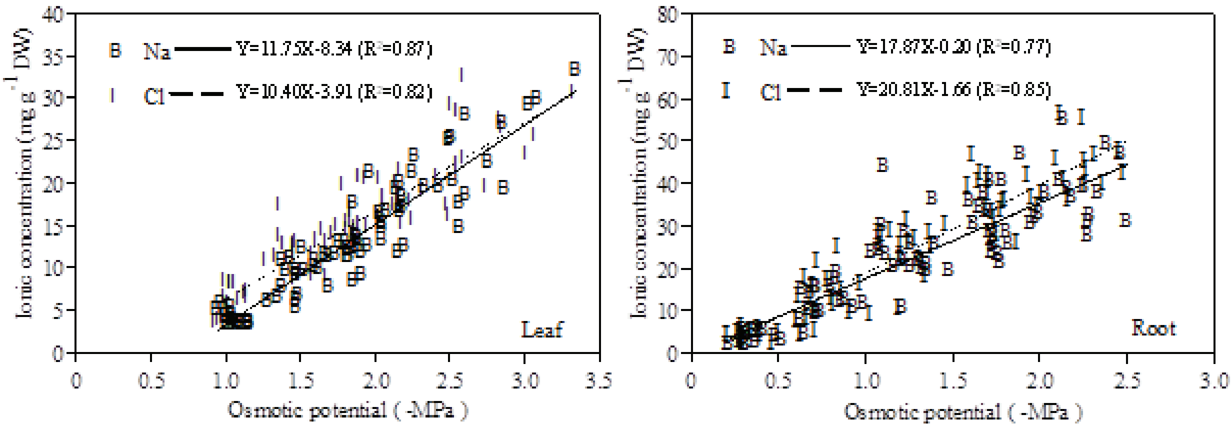

Figure 4: Relationships between the measured osmotic potential and ionic ($Na^+$and Cl^-) concentrations in the leaf and root of the four bermudagrass cultivars at 0, 100, 200, 300, and 400 mmol L^{-1} NaCl (n = 80).

Ion excretion by the leaf salt glands

Salt crystals were visible on the leaves of all cultivars growing in saline solution. Salt glands were present on both the abaxial and adaxial leaf surfaces of all four cultivars. The glands were situated atop the leaf epidermis, and were recumbent. Glands were bicellular, with a basal cell and a cap cell, and were surrounded by numerous papillae (Fig. 5).

Compared to control, leaf salt gland Na^+ excretion increased significantly from 100 mmol L^{-1} NaCl (Fig. 6). The amount of Na^+ excretion was significantly higher in Riviera and Blackjack

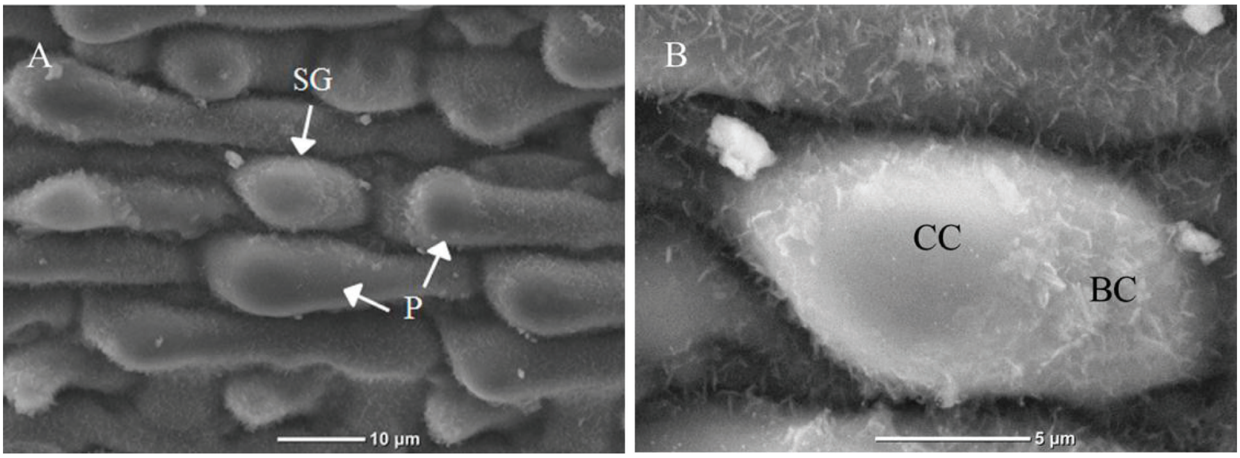

Figure 5: Scanning electron micrographs of the adaxial leaf surface of Riviera bermudagrass at 300 mM NaCl. SG, salt gland; P, papillae; CC, Cap cell; BC, Basal cell.

than in Savannah and Sundevil 2. The Cl^- excretion in Riviera and Blackjack increased with increasing salinity, and was higher than in Savannah and Sundevil (Fig. 6). The Cl^- excretion in Savannah increased to 200 mmol L^{-1} NaCl and then decreased. The Cl^- excretion in Sundevil 2 did not change significantly with increasing salinity. The Cl^- excretion exhibited significant differences among cultivars under salinity stress, especially at higher salinity levels.

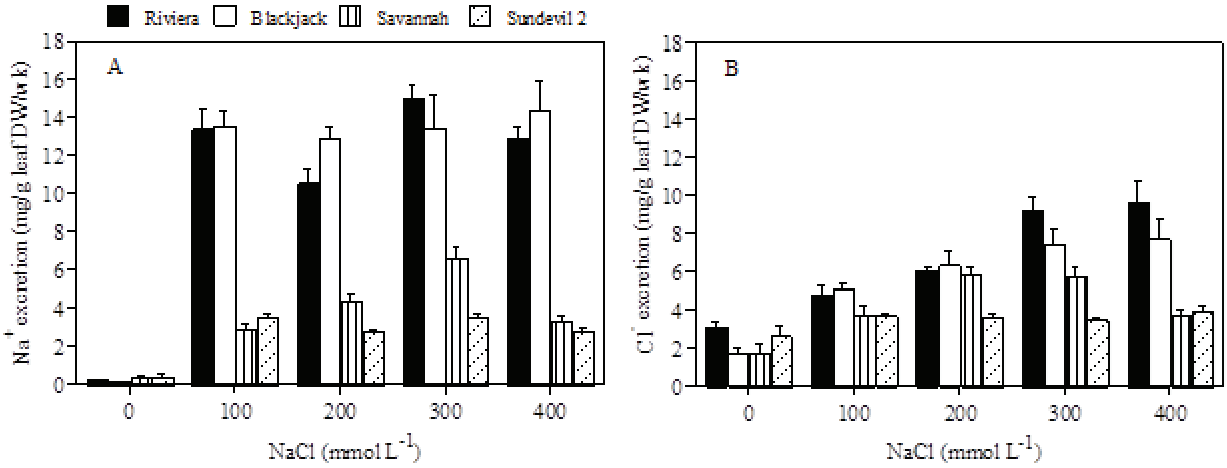

Figure 6: Leaf salt gland Na^+(A) and Cl^-(B) excretion rates of the four bermudagrass cultivars at 0, 100, 200, 300, and 400 mmol L^{-1} NaCl. Data are the means ± standard error (n = 6).

Discussion

Salt stress results in a considerable decrease in the fresh and dry weights of plants due to an inhibition of cell division and loss of cell turgor (Chartzoulakis and Klapaki 2000; Neumann *et al.* 1988). Our results show that shoot FW and DW of all four bermudagrass cultivars were significantly inhibited by salinity stress (Table 1). There was a large difference in salt tolerance among four bermudagrass cultivars. The order was: Riviera > Blackjack > Savannah > Sundevil 2.The root FW and DW and root length increased at moderate salinity levels (Table 1).This root growth stimulation in all four cultivars may be an adaptive response to salinity stress, because a concurrent increase in root growth and decrease in shoot growth would increase the root/shoot ratio, and would therefore increase water absorption to alleviate osmotic stress. Mechanisms of adaptation to salinity stress can be very specific for different cultivars. For example, Riviera had a higher shoot weight than the other cultivars at the same level of salinity stress, and its root weight and root length increased markedly to compensate for the greater evaporative surface of the shoots. This root growth stimulation under moderate salinity has been reported previously in relatively salt-tolerant grasses (Alshammary *et al.* 2004; Dudeck *et al.* 1983; Dudeck and Peacock1993).

Bermudagrass maintains high relative water content which may be responsible for higher growth rates under salt stress. Osmotic stress due to a lack of osmotic adjustment inhibits water uptake and can lead to physiological drought (Marcum 1999). However, the osmotic potentials in the shoots and roots were more negative than the corresponding level in the growing media in all cultivars, which indicates that all cultivars achieved complete osmotic adjustment. Water contents in the shoots and roots of all four cultivars decreased with increasing salinity (Table 1), indicating that the cultivars may have achieved complete osmotic adjustment by solute accumulation and tissue dehydration. Marcum and Murdoch (1990) reported that osmotic adjustment of bermudagrass was not achieved exclusively by solute accumulation but also by tissue dehydration. The most salt-tolerant cultivar, Riviera, maintained a less negative osmotic potential, which may have resulted from the low ionic concentrations and high relative water contents in this cultivar. In contrast, the most salt-sensitive cultivar, Sundevil 2, exhibited the lowest osmotic potential. This was due to relatively high ionic concentrations concurrent with very low relative water contents. Our results suggested that Riviera might have achieved its superior osmotic adjustment and salt tolerance by greater solute accumulation and less tissue dehydrationthan in the more salt-sensitive cultivars.

The salinity tolerance was significantly negatively correlated with the tissue Na^+ and Cl^- concentrations in all four cultivars. Riviera accumulated less Na^+ and Cl^- than did Sundevil 2, especially at higher NaCl concentrations (Fig. 1). Salinity tolerance in grasses has been associated with the exclusion of Na^+ and Cl^- from the shoots (Marcum 2006; Marcum and Murdoch 1994). In this study, the most salt-tolerant cultivars had higher rates of Na^+ and Cl^- excretion by salt gland than the least salt-tolerant cultivars (Fig. 6). Riviera had higher Na^+ and Cl^- excretion rates and maintained lower leaf ion concentrations, resulting in superior salinity tolerance. This result is consistent with previous results for 57 zoysiagrass genotypes (Marcum *et al.* 1998) and 35 bermudagrass cultivars (Marcum and Pessarakli 2006), indicating that salt gland excretion efficiency is an important factor in the process of salt ion regulation and the resultant salinity tolerance. Marcum and Pessarakli (2006) suggested that salt gland excretion efficiency might be an effective diagnostic criterion for selecting salinity-tolerant bermudagrass cultivars for breeding. Therefore, salt gland characteristics such as density and size deserve further attention.

Riviera also accumulated the lowest amounts of Na^+ and Cl^- in its roots. In all cultivars, the concentrations of Na^+ and Cl^- in the roots were higher than those in the leaves (Figs. 1, 3). These results suggest that the high salinity tolerance of Riviera may result from its ability to reduce uptake of Na^+ and Cl^- better than the other cultivars. The ability to prevent the entry of Na^+

and Cl^-into the leaves was strong in Riviera. Therefore, preventing $Na^+$and Cl^-transport from the roots to the leaves appears to be an important mechanism that results in the different salt tolerance levels among the bermudagrass cultivars.

Potassium concentrations in leaves and roots decreased significantly with increasing salinity, and those in the leaves were higher than those in the roots in all four cultivars (Fig. 2). Potassium played an essential role in the growth of all four cultivars under salinity stress. Potassium is involved in the activation of several enzymes, in membrane transport and in the maintenance of osmotic potential in vacuoles and guard cells (Lee *et al.* 2007; Marschner 1995). The K^+ concentration differed significantly among cultivars, and appeared to be related to salt tolerance. Riviera had higher leaf and root K^+ than the other cultivars. This suggests that the roots of salt-tolerant cultivars selectively accumulate K^+ and transport it to the leaves.

Maintaining a high concentration of K^+ and a low concentration of Na^+ in the cytoplasm is an important physiological response to salinity stress (Tester and Davenport 2003). Bermudagrass might achieve the regulation of toxic ions by the leaf salt glands and by transporting K^+into the leaves to increase the K^+/Na^+ ratio. 'C291' bermudagrass exhibited both ion regulation mechanisms, but to much less extent (Chen *et al.* 2009)). In present study, four bermudagrass cultivars had different ion regulation capacities. Riviera took up less Na^+ and Cl^- than the other cultivars under the same level of NaCl stress. High rates of Na^+ and Cl^- excretion by leaf salt glands were associated with lower leaf Na^+ and Cl^- concentrations, indicating that salt gland excretion efficiency is an important factor in the regulation of ions and the resultant salinity tolerance of bermudagrass. Riviera and Blackjack maintained higher Na^+ and Cl^-excretion rates than Savannah and Sundevil 2 at the same level of salt stress. Riviera apparently has a strong capacity for K^+ accumulation and for K^+ transport to the leaves as a nutrient and osmoregulator.

In summary, the four bermudagrass cultivars exhibited a broad range in salinity tolerance. A cultivar's salinity tolerance is based on its ability to (i) accumulate Na^+ and Cl^- in the roots and limit their transport to the leaves, (ii) maintain selectivity of K^+ over Na^+ in the leaves, and (iii) maintain a higher salt excretion capacity via the leaf salt glands.

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Alfalfa is sensitive to salinity but tolerant to sodicity

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Abstract

Salinity inhibits water uptake by plants owing to osmotic stress. Sodicity causes nutritional disorders owing to Na+ toxicity and high pH. Although the characteristics of salinity and sodicity differ, it seems that the tolerance of plants to both stresses should be the same. Yet, although barley (*Hordeum vulgare*) is classified as tolerant to salinity and sodicity and beans (*Phaseolus vulgaris*) are classified as sensitive to both, alfalfa (*Medicago sativa*) is classified as sensitive to salinity but tolerant to sodicity. We grew these species under high osmotic or sodic conditions to elucidate their growth responses to each and to reveal which factors are responsible for tolerance. We used polyethylene glycol solution to simulate salinity through its osmotic effects, and mixed soil with Na_2CO_3 to create high Na+ and high pH conditions. Under high osmotic strength, barley maintained a high water content and high water uptake, and its growth was not reduced. In contrast, alfalfa and beans showed decreased water content and water uptake. Sodicity did not affect the growth of alfalfa, which was able to maintain lower Na and higher Fe accumulation. In contrast, it increased Na and decreased Fe in barley and beans, and decreased their growth. We conclude that differential physiological responses of plants to high osmotic strength and sodicity clearly explain their tolerance to these stresses.

Introduction

Salt-affected soils can be saline or sodic or both. Both types are widely distributed in drylands and impose major stresses that inhibit plant growth and reduce crop productivity. Soil with an electrical conductivity (EC) of its saturation extract that exceeds 4 dS m^{-1} is classified as saline (US Salinity Laboratory Staff 1954). Salinity refers to “concentrations of soluble salts so high as to affect significantly the colligative properties of the solution to which the roots are exposed, speci
by reducing its osmotic potential” (Tanji 1996). Salinity inhibits water uptake by plants and triggers leaf wilting and reduction of photosynthesis. Soil with a sodium adsorption ratio (SAR) higher than 15 is classified as sodic (US Salinity Laboratory Staff 1954). Sodicity is due to high activity of Na^+, in particular in the absence of an osmotic component (Tanji 1996). Sodicity causes Na toxicity and disturbs the homeostasis of essential cations such as K^+, Ca^{2+}, and Mg^{2+}, resulting in their deficiency (Niu *et al.* 1995, Rodriguez-Navarro 2000). Sodic soil is also accompanied by an increase in pH due to high concentrations of CO_3^{2-} and HCO_3^-, and induces the deficiency of micronutrients such as Fe, Mn, Cu, and Zn (Gupta *et al.* 1989, Jumberi *et al.* 2001). Therefore, sodicity causes nutritional disorders (Curtin and Naidu 1998). To cope with these stresses, plants can counter both through mechanisms such as osmotic adjustment, succulence of organs, and the exclusion of Na+ (Binet 1985, Gorham et al. 1990, Ottow *et al.* 2005).

The relative tolerance of plants to salinity (Maas 1984) and sodicity (Pearson 1960), as assessed from biomass production, has been reported for a large number of species. In most plants, the ratings are the same between salinity and sodicity; for example, barley is tolerant, beans are sensitive. This might create a misconception that salinity-tolerant plants must be sodicity-tolerant and vice versa, although the effects of each are different. In fact, some plants are classified differently: for example, alfalfa is sensitive to salinity and tolerant to sodicity, and spinach is moderately sensitive to salinity and moderately tolerant to sodicity (Maas 1984; Pearson 1960).

Most studies of salt stress use NaCl, even though it induces both osmotic and Na stresses. To elucidate the responses of plants to the osmotic aspect of salinity, we used polyethylene glycol (PEG). As sodic conditions cannot be reproduced in solution culture, we prepared a high-Na^+, high-pH soil with Na_2CO_3. The purpose of this study was to clarify the physiological responses of barley, alfalfa, and beans to high osmotic strength and high sodicity in order to reveal what determines tolerance to each.

Materials and methods

Plant materials

Barley (*Hordeum vulgare* L. 'Fiber snow'), alfalfa (*Medicago sativa* L.), and beans (*Phaseolus vulgaris* L. 'Nahl') were grown in October in a greenhouse of Tottori University, Tottori, Japan.

Growth in high-osmotic-strength solution

Seeds were germinated in vermiculite. Two-leaf seedlings of each species were transferred into sixteen 4-L plastic pots at 5 plants per pot with nutrient solution (Ohori and Fujiyama 2011), the pH of which was adjusted to 5.0 with KOH solution. The nutrient solution was continuously aerated and replaced weekly. When seedlings were 10 cm high, the nutrient solution in half the pots was replaced with polyethylene glycol (PEG, mol. wt. 6000), iso-osmotic to 80 mol m^{-3} NaCl; the nutrient solution in the other pots remained the same. The osmotic potential of the solutions as measured with a vapor pressure osmometer (Vapro Osmometer 5520, Wescor, Inc., South Logan, UT, USA) was –0.10 MPa in the control solution and –0.46 MPa in the PEG solution.

Each treatment consisted of 4 replicates (pots). Plants were harvested at 1 and 7 d after the start of treatment and were separated into shoots and roots. Fresh weight (FW) was measured immediately. Dry weight (DW) was measured after oven-drying at 70 °C for 2 d. The percentage water content (WC) was calculated from FW and DW.

To investigate the effect of high osmotic strength on water uptake, we transferred plants into solutions in 250-mL plastic bottles at one plant per bottle, with 4 replicates per treatment. The amount of solution taken up by the roots 1 d after the start of treatment was calculated as the difference in volume.

Growth in sodic soil

Soils were prepared from air-dried Tottori dune soil by the addition of various salts (Table 1). Strictly speaking, the sodic soil was not sodic as defined (EC < 4.0, pH > 8.5, SAR > 15), but was close (EC = 4.9, pH = 8.2, SAR = 53.5). The EC, pH, and concentrations of water-soluble cations in each soil were measured in saturation extracts (US Salinity Laboratory Staff 1954). The SAR was calculated as $[Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2}$.

Seeds were sown in 6-cm-diameter PVC pots filled with control soil. Two weeks after germination, six seedlings of each species were transplanted into 4-L pots filled with control or sodic soil, with four replicates (pots) per treatment. Shoots of 2 plants in each pot were harvested at 4, 14, and 28 d after transplanting. Roots were harvested only at 28 d. The FW and DW of shoots and roots were measured as above.

Table 1: Salts added to soils and resultant chemical properties

	Amount of salt (cmol kg^{-1})						EC (25 °C) dS m^{-1}	pH	SAR
	$CaCl_2 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	Na_2CO_3	$NH_4H_2PO_4$	NH_4NO_3	K_2SO_4			
Control	0.10	0.10	–	0.18	0.36	0.13	3.2	5.4	2.6
Sodic	0.20	0.20	0.75	0.18	0.36	0.13	4.9	8.2	53.5

Chemical analysis of plants in sodicity experiment

Plant parts were decomposed in sulfuric acid and hydrogen peroxide at 200 °C. Na and K concentrations were determined by atomic absorption spectrophotometer (Polarization Zeeman Atomic Absorption Spectrophotometer Z-6100, Hitachi, Tokyo, Japan). Fe concentration was measured by inductively coupled plasma mass spectrometer (Rigaku CIROS CCD, Rigaku, Tokyo, Japan).

Statistical analyses

Statistical analyses were carried out in GraphPad Prism 5.04 software (GraphPad Software, Inc., La Jolla, CA, USA). All data are presented as means ± standard deviation (SD). Student's *t*-test was used to test the significance of differences at 5%.

Results

Effects of high osmotic strength on plant growth

Relative to the control, PEG significantly decreased the shoot FW of alfalfa and beans at both 1 and 7 d, whereas that of barley was unaffected (Table 2); it also significantly decreased the DW of alfalfa and beans at 7 d, although barley remained unaffected. PEG significantly reduced the shoot WC of alfalfa to 78% and of beans to 85% at 1 d, and to 75% and 59% at 7 d, but that of barley was unaffected. PEG significantly decreased water uptake by all species at 1 d (Fig. 1), more so in alfalfa and beans.

Effects of sodicity on plant growth

Relative to the control, sodicity did not affect the shoot DW of any species at 4 d (Fig. 2); it significantly decreased that of beans at 14 d, and that of barley and beans at 28 d. Alfalfa was not affected.

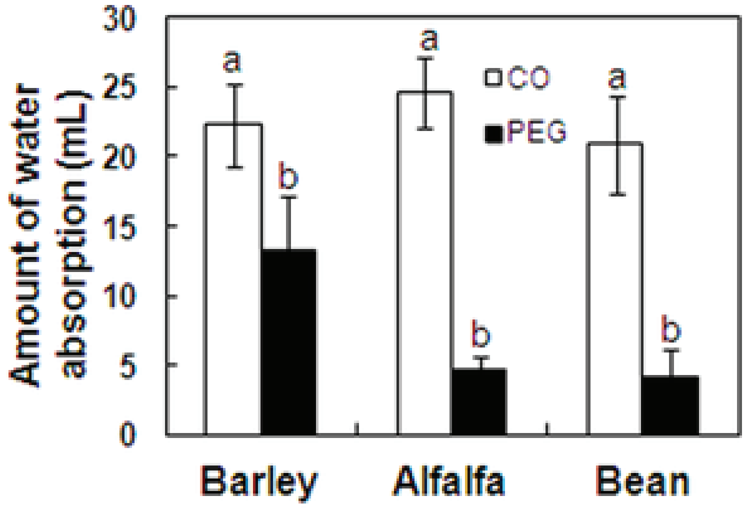

Figure 1: Root water uptake after 24 h in control or polyethylene glycol (PEG) solution. Within treatments, bars with the same letter are not significantly different (P = 0.05; Student's t-test). Values are means ± SD; n = 4.

Table 2: Fresh weights (FW), dry weights (DW), and water contents (WC) of shoots in control and high-osmotic-strength (PEG) treatments. Values within columns followed by the same letter are not significantly different (P = 0.05; Student's t-test)

	1 day			7 days		
	FW (g plant^{-1})	DW (g plant^{-1})	WC (%)	FW (g plant^{-1})	DW (g plant^{-1})	WC (%)
Barley						
Control	3.19 a	0.20 a	90.4 a	3.67 a	0.35 a	90.5 a
PEG	3.36 a	0.24 a	89.4 a	2.09 a	0.32 a	84.6 a
Alfalfa						
Control	3.42 a	0.50 a	85.5 a	4.83 a	0.83 a	82.8 a
PEG	1.61 b	0.52 a	67.0 b	1.21 b	0.45 b	62.3 b
Bean						
Control	4.23 a	0.39 a	90.8 a	6.93 a	0.76 a	89.0 a
PEG	1.59 b	0.36 a	77.0 b	0.96 b	0.41 b	52.1 b

Effects of sodicity on Na and K concentrations

Sodicity significantly increased the Na concentration in shoots and roots of all species at 28 d (Table 3). The Na concentration was lower in shoots than in roots of alfalfa and beans, but higher in shoots of barley. Sodicity decreased the shoot K concentration in barley, but it increased those of alfalfa and beans. In contrast, it did not affect the root K concentration of barley or alfalfa, but it decreased that of beans. The sodic-to-control ratios of Na were all <~10 except that in shoots of beans, which was 75.2 (Fig. 3A). Sodicity significantly increased the shoot Na/K ratio in all species, but the effect was smallest in alfalfa (Fig. 3B).

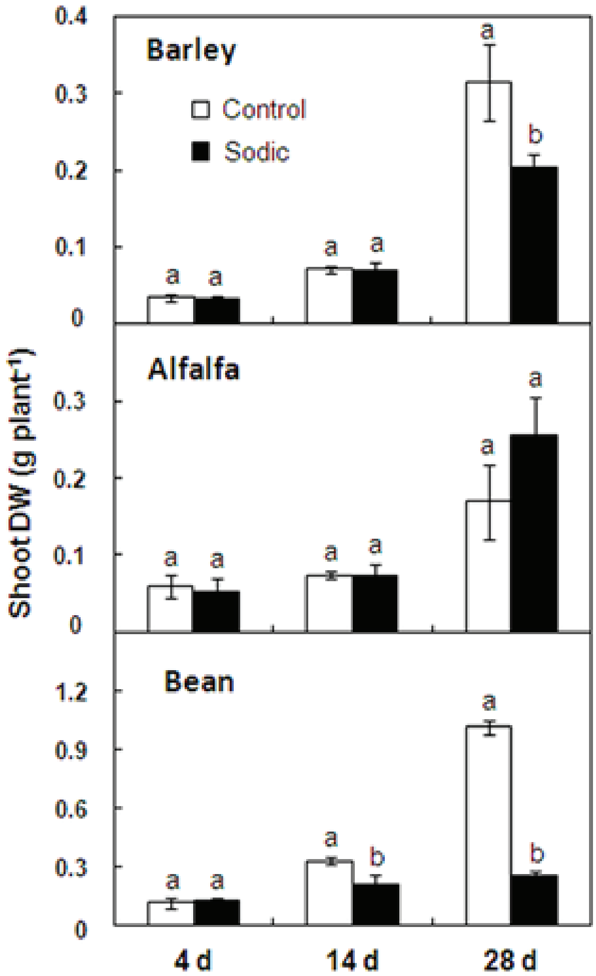

Figure 2: Shoot DW under control and sodic conditions at 4, 14, and 28 d. Within columns, bars with the same letter are not significantly different ($P = 0.05$; Student's *t*-test). Values are means ± SD; $n = 4$.

Table 3: Na and K concentrations (mol kg^{-1} DW) 28 d after the start of treatment. Values within treatments followed by the same letter are not significantly different ($P = 0.05$; Student's *t*-test)

	Shoot		**Root**	
	Na	**K**	**Na**	**K**
Barley				
Control	0.30 b	1.93 a	0.22 b	0.57 a
Sodic	2.61 a	0.78 b	0.96 a	0.45 a
Alfalfa				
Control	0.09 b	0.77 b	0.20 b	0.63 a
Sodic	0.56 a	0.94 a	0.88 a	0.34 b
Bean				
Control	0.02 b	0.48 b	0.18 b	0.44 a
Sodic	1.13 a	0.85 a	1.86 a	0.22 b

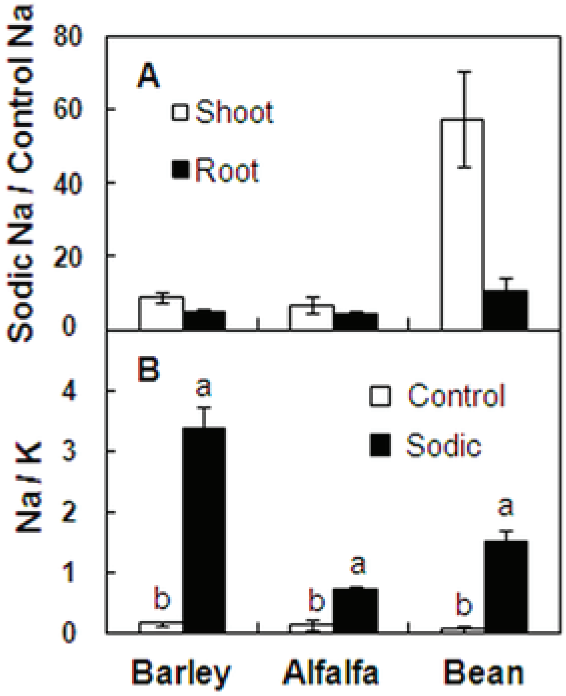

Figure 3: (A) Ratios of Na concentrations in shoots and roots in the sodic treatment to those in the control treatment. **(B)** Shoot Na/K ratios 28 d after the start of treatment. Within species, bars with the same letter are not significantly different ($P = 0.05$; Student's t-test). Values are means ± SD; $n = 4$.

Effects of sodicity on Fe concentration

The high pH in the sodic soil significantly decreased the Fe concentration of barley, but not of alfalfa or beans (Fig. 4).

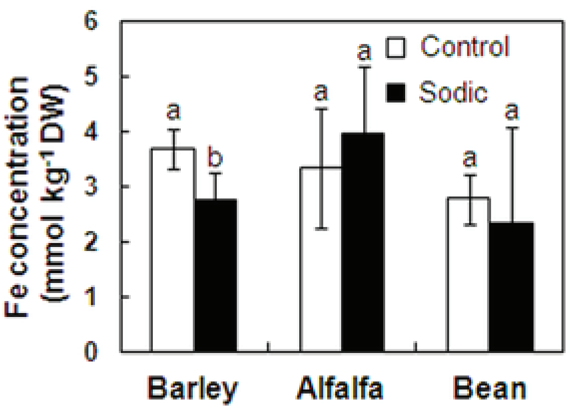

Figure 4: Fe concentration of shoots 28 d after the start of sodicity treatment. Within species, bars with the same letter are not significantly different ($P = 0.05$; Student's t-test). Values are means ± SD; $n = 4$.

Discussion

Responses of plants to high osmotic strength

PEG, which causes high osmotic stress in plants, considerably suppressed the growth of alfalfa and beans, but the growth of barley was not affected (Table 2). This supports the previous rating of barley as tolerant and alfalfa and bean as sensitive to salinity (Maas 1984).

In general, osmotic stress rapidly reduces WC (Lissner *et al.* 1999) and suppresses shoot growth (Westgate and Boyer 1985, Sharp *et al.* 1988). PEG severely inhibited water uptake by all three species (Fig. 1), although barley maintained a high WC (Table 2). The suppression of transpiration due to stomatal closure is the main short-term tolerance response when plants are exposed to high osmotic stress (Ludlow 1980). This likely explains how the barley was able to avoid significant growth reduction at 7 d under osmotic stress.

Osmotic adjustment through the accumulation of solutes confers tolerance to both salinity and drought stress. It can be accomplished by the uptake of inorganic ions and their compartmentation in vacuoles (Prat and Fathi-Ettai 1990). In addition, plants synthesize organic compounds such as amino acids and sugars (Hsiao *et al*. 1976, Munns 1988, Popp and Albert 1995). PEG does not penetrate intact plant tissues (Michel and Kaufmann 1973, Carpita *et al.* 1979) and therefore does not act as an osmolyte. Therefore, barley may adjust its osmotic pressure by synthesizing osmolytes effectively, which would allow better water uptake than in salinity-sensitive alfalfa and bean (Table 2, Fig. 1).

Responses of plants to sodicity

On the basis of shoot DW, we classified alfalfa as tolerant, barley as moderately tolerant, and beans as sensitive to sodicity (Fig. 2), similar to a previous assessment (Pearson 1960).

Excessive Na in leaves may inhibit enzyme activity or trigger injury (Flowers and Yeo 1986, Munns 1988). Therefore, the control of Na accumulation in leaves is important for overall sodicity tolerance (Munns 2002). In addition, low Na and high K in the cytoplasm are crucial to maintaining various enzymatic processes (James *et al.* 2006). This balance may be regulated by the selective uptake of K. Alfalfa accumulated more Na in roots than in shoots, it accumulated more K than Na in shoots under sodicity (Table 3), and it had the lowest shoot Na/K ratio under sodicity (Fig. 3B). These results indicate that alfalfa is sodicity tolerant because it can protect itself from Na toxicity by inhibiting Na translocation to shoots, and can maintain a low Na and a high K concentration in shoots by the selective uptake of K.

Barley maintained constant DW under high sodicity, although it accumulated more Na and less K in shoots under sodicity than in control (Table 3). Na compartmentation in shoots may contribute to the sodicity tolerance of barley, as barley is reported to accumulate high concentrations of Na in mesophyll vacuoles under 150 mM NaCl treatment, and yet still maintain 83% of the net rate of photosynthesis of control plants (Fricke *et al.* 1996).

The shoot DW of beans under high sodicity at 28 d was only 25% of that in the control (Fig. 2C). The beans accumulated 57 times as much Na in shoots and 10 times as much in roots as in the control (Fig. 3A). This excessive Na accumulation in shoots shows that beans cannot regulate Na uptake to an acceptable level for growth.

Fe is an essential microelement that is involved in electron transfer reactions and in the biosynthesis of chlorophyll (Rüdiger and Udo 2003). Therefore, the maintenance of Fe concentration at high soil pH is critical. The release of phytosiderophores and phenolics from plant roots acidifies the rhizosphere, increasing the availability of Fe (Römheld 1987; Marschner and Römheld 1994). Only the barley Fe concentration was decreased significantly at high soil pH (Fig. 4). Fe-deficient barley releases the phytosiderophore mugineic acid from its roots to solubilize Fe by chelation (Römheld and Award 2000, Schaaf *et al.* 2004); however, the addition of Na inhibited the release of phytosiderophores by Fe-deficient barley (Yousfi 2007), which may explain the reduction of Fe concentration that we observed.

Fe was not significantly reduced in alfalfa under high soil pH (Fig. 4). Red clover can dissolve Fe by secreting phenolics from its roots (Jin 2007). Alfalfa might do something similar. The Fe concentration of beans was less affected by sodicity than that of barley (Fig. 4). This result might be explained by the loss of a "dilution effect". A dilution effect is a reduction in the concentration of an element that is brought about by a DW increase relative to nutrient uptake (Jarrell and Beverly 1981). The shoot DW of beans was considerably decreased (Fig. 2C), canceling any dilution effect. Thus, both Fe uptake and growth were inhibited by sodicity.

In conclusion, our results clearly show that growth responses of barley, alfalfa, and beans differ between conditions of high osmotic strength and sodicity. Plants' tolerances to salinity and sodicity depend on their ability to counter osmotic stress, Na stress, and high pH stress.

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Evaluation of water status indicators in olive trees under different water regimes

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Abstract

Physiological responses of olive (*Olea europaea L.*) trees under different water regimes (irrigated and rainfed) was monitored through the selected indicators (the soil water content, the tree stem water content, the sap flow and the leaf conductance) at the experimental field of the CIHEAM-IAMB from March to August 2012. The difference in response of olive trees under two water regimes was significant in terms of four water status indicators. In addition, the growth of olive tree (leaf area and fruit establishment) was also different. The water status indicators responded differently to both the application of water (by irrigation) and to the moment in which water stress appeared. A sort of "critical point" of soil water content for olive was detected for this field, and it was consistent with the one calculated from the retention curve. The values of water status indicators were found to be clearly correlated within each other, following similar paths and trends for both water regimes until a critical value of the soil water content was reached. Close to this point, all the plant water status indicators showed a clear trend of reduction to minimal values. The differences in the physiological responses of olive trees under irrigated and rainfed conditions can be evaluated by means of integrated observations of water movement in soil-plant –atmosphere continuum. The tree stem water content and/or the sap flow could be effectively used to evaluate the occurrence of water stress in olive, better still with additional data on the soil water content and/or the evaporative demand of the atmosphere. The effectiveness of irrigation strategies to avoid water stress can be confirmed by the use of such indicators.

Introduction

Plants are exposed to water stress in arid regions. Trees in dry land have specific responses to such stress to survive under severe conditions. Olive tree (*Olea europaea* L.) is one of the world's oldest species and is the best crop adapted to the semi-arid Mediterranean environments. Even though olives have morphological and physiological characteristics for adaptation to the Mediterranean land and climate, irrigation remains essential to ensure optimal growth and yield. Irrigation scheduling techniques are based on the plant's actual needs and the optimal use of water (Fernandez *et al*. 2001). Efficient water use is absolutely imperative for the sustainable irrigation of olives in the Mediterranean and other areas. This can be performed by understanding the temporal water use by olive trees because olives change their water use with the surrounding environment as a strategy for tolerating water stress. Identifying plant water stress is important to determine plant water use. If we could evaluate the level of water stress by measuring water status, olives can be managed easily with irrigation scheduling that is based on the plant's actual water deficit. Thus, efficient irrigation can be achieved by observing several water status indicators.

Water circulates in the soil-plant-atmosphere continuum. Transpiration depends on the evaporative demand of the atmosphere and water runs through the plan's interior from the soil to the atmosphere. Hillel (1998) described a plant as a "pathway of water". Additionally, Connor and

Fereres (2005) studied the relationships between plant physiology and water stress. Soil water content in the root zone, leaf conductance, sap flow, and the tree stem water content are examples of some of the most widely used indices that can monitor water status and fluxes through the soil-plant-atmosphere continuum. Soil water deficits and the consequently lowered soil water potentials are usually used to determine the underlying stresses in the system. For example, Farías and Acevedo (2004) monitored the soil water content by Time Domain Reflectometry in a grape orchard and concluded that the water supply can increase water use efficiency.

Monitoring the soil water content in the root zone is a useful method for irrigation scheduling. However, woody plants store water and consume it in such a way that it initially corresponds to the evaporative demands of the atmosphere. Then they absorb water from soil to compensate for the lack of water in the tree stem (Hernandez-Santana *et al.* 2007). Therefore, many researchers have focused on the water condition in the tree stem. Nadler *et al.* (2003) showed that understanding the condition of the stem water content is useful for clarifying the actual water deficit. Other experiments used sap flow in the stem (Fernández *et al*. 2001).

In this paper, we observed the response of the tree stem for the changes in the soil water content obtained by irrigation. Through a series of continuous measurements of the water status in the soil-plant-atmosphere continuum, we clarified how each indicator reacts to different water management practices (irrigation and rainfed) and their interrelation.

Materials and methods

Experimental arrangement

The experiment was conducted in 2012 at the Mediterranean Agronomic Institute of Bari (IAMB), Valenzano (Bari), in southern Italy, which is characterized by a typical Mediterranean semi-arid climate. The annual mean rainfall is about 586 mm, which is distributed mainly during winter; summer is dry and hot. The experimental crop was olives (*Olea europaea* L.), which are widely cultivated in the Mediterranean climate including the dry lands. The experimental field's olive trees were planted about 30 years ago. The variety was 'Coratina'. The field was 56 m long and 60 m wide (Fig.1). There were ten lines in the field and fourteen trees in each line. Two specific lines were selected. One was connected to the irrigation network, and the other was left without any irrigation source to create irrigated and rainfed conditions. Four trees were chosen from each line and irrigated 12 times (June 1, 5, 6, 20, 21, and 27; July 7, 8, 26, and 27; and August 10 and 30) during the experimental period and the total irrigation water supply was 281 mm.

Water status indicators

We measured the soil and stem water content, stomatal conductance, and sap flow as water status indicators. The soil and the stem water content were measured from March to September 2012. The stomatal conductance was measured from June to September. The sap flow was measured from July to September. All indicators were measured under both irrigated and rainfed conditions. Measurements were normally performed twice a week, but after irrigation and rainfall events we monitored the stem and soil water content every day until no more variations were observed. Additional intensive measurements were arbitrarily conducted for a couple of hours in the daytime.

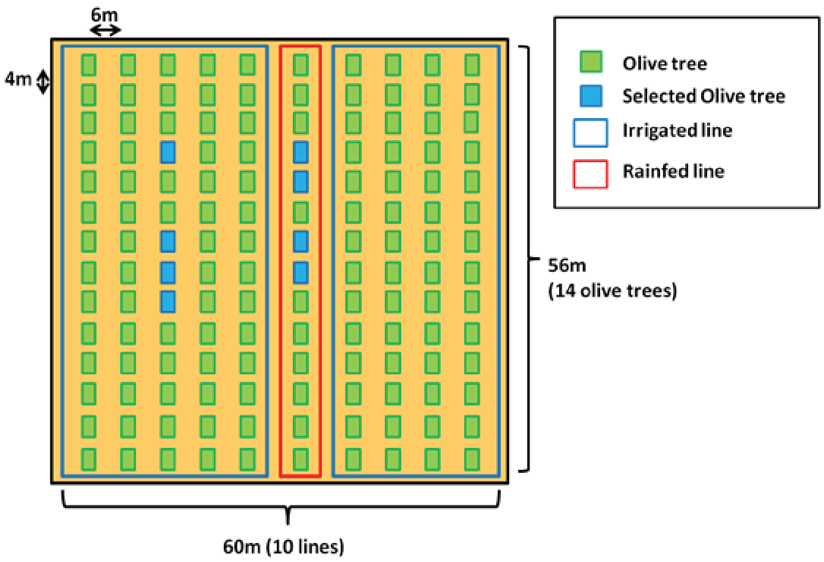

Figure 1: Experiment field.

The soil water contents at 10, 20, 30 and 40 cm depth were measured by an Amplitude Domain Reflectometry (ADR) sensor called the Profile Probe (PR2/4, Delta-T Devices Ltd.). The data were recorded by a handy logger (HH2, Delta-T Devices Ltd). Measurements were done at three locations around a tree, forming a 120° angle among the access tubes. The access tubes were 0.7 m from the tree.

The tree stem water content was measured using an Amplitude Domain Reflectometry (ADR) sensor with detachable probes (Photo 1). The water content was calculated by measuring the dielectric constant because it is a related to the stem water content. After previously calibrating the relation, the water content can be monitored by the ADR method. Since the dielectric constants are measured by touching the ADR sensor and the probes (Photo 2), it is reasonable for multi-points measurements. The water content was measured at two points (at a height of 0.5 and 1 m) on each tree. The length of the detachable probes was changed depending on the diameter of each tree.

Photo 1: Detachable probes

Photo 2: The Amplitude Domain Reflectometry sensor

We measured the sap flow by a sap flow sensor with a stand alone type meter (SFM1 sap flow meter, ICT International). The data-logger, which measures the sap flow and the transpiration, was integrated with the sensor. The sap flow meter was installed into two trees for the irrigated and rainfed treatments and measurements done every 30 minutes. The sap flow meter measures the fast and late flow velocity not only of thick trees but also branches and roots with a small trunk diameter. The probe of the Heat Ratio Method (HRM) has two temperature meters. Therefore, the sap flow gradient in the radial direction of the trunk and the stem is precisely measured to observe the sap flow differences by depth. The sap flow meter, which is comprised of three 35-mm probes, is connected with a 16 bit microprocessor. These three probes are installed in tandem into a tree. The upper and lower probes are thermistor thermometers with high precision that measure the stem temperatures at 7.5 and 22.5 mm from the top of each probe (Fig. 2). The middle probe is a line heater to generate accurate heat pulses of the sap flow.

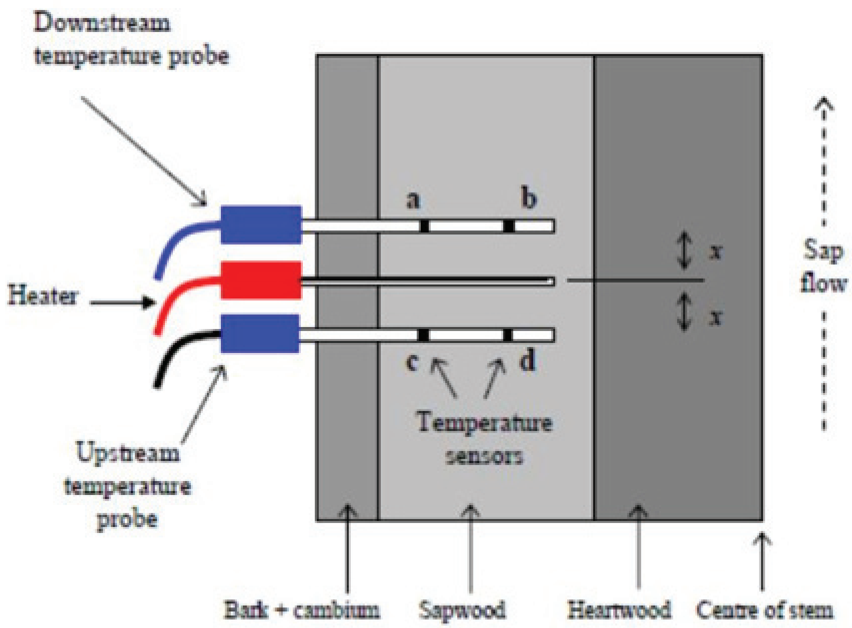

Figure 2: Explanation of sap flow sensor

We evaluated the occurrence of the water stress by measuring the stomatal conductance with a leaf porometer (SC-1, Decagon devices) at midday on the lower surface of the youngest fully expanded leaf. The measurement positions were 1.5 m high in each tree. Three leaves were used on each tree.

The soil water retention curve was developed to determine the soil physical properties in the fields. Soil samples from 10-20-30-40 cm depths were analyzed in the laboratory with the Stakman method (Beqaj 2010). The analytical expression of the soil water retention curve was obtained using the van Genuchten (1980) method, based on the following equation:

$\theta = \theta_r + \left\{(\theta_s - \theta_r)\left[\frac{1}{1+(\alpha h)}\right]\right\}$, where $\theta_s = Saturated\ water\ content;$

$\theta_r = Residual\ water\ content;\ \alpha, n, m = Empirical\ constant.$

Identified parameters for the van Genuchten (VG) function are given in Table 1.

Table 1: Identified parameters of VG function

θ_s	θ_r	α	n	m
0.485	0.060	0.070	1.174	0.148

Calibration

Since the soil water content was measured by ADR sensor which measures dielectric constant and outputs it as voltage it had to be caliberated to convert the observed value to water content. This was done by relating the ADR sensor values with the volumetric water content of the soil samples taken by depth near the access tube. The calibration samplings were done six times under different soil water conditions during the experiment (May 28, June 5 and 25, July 8, August 1 and 24).

For stem water content**,** calibration curves were made for each probe to convert the output from the ADR sensor into the volumetric water content in the trees. A piece of the olive stem of the same variety was prepared for making the calibration curves. Probes of 8, 9, 10, and 11 cm size were inserted into the piece. After that, the volume of the stem's piece was measured by the dipping method. The piece was put in water for two weeks. Its dielectric constant and weight were regularly measured during the drying process. Then the piece was completely dried in an electric oven at 105°C for 24 hours, and its dry weight was observed to calculate its volumetric water content.

No information could be collected on the yield of the olive trees because the harvest was planned outside of our observational period (November). We did manage to obtain some quantitative information on the effect of the treatments by a simple biometric analysis of the branches and the tree leaves. At the end of the observational period, on September 27, two representative branches were taken from the third main branch of each tree, and the number and the weight of the leaves and the fruits were measured with the leaf area.

Results and discussion

Soil water retention curve

The soil water retention curve is shown in Figure 3, where the experimental data were fit by the van Genuchten (VG) model. From the VG curve, the saturated water content, the field capacity (FC), and the wilting point (WP) were determined, which were about 0.48 $cm^3 cm^{-3}$, 0.30 $cm^3 cm^{-3}$, and 0.18 $cm^3 cm^{-3}$, respectively. Then TAW, RAW, and the threshold corresponding to RAW were calculated from these values which were 120 mm/m, 80 mm/m, and 0.22 $cm^3 cm^{-3}$,respectively.

Calibration

The calibration curve for soil water content using the PR2/4 probe is shown in Figure 4. The calibration curves for each depth was nearly the same, hence same curve was used for each depth. The regression equation was: $y = 0.032e^{0.0032x}$.

We calibrated the tree stem water content from March 23 to June 20. The calibration curves are shown by depths in Figure 5. The following regression equations were then developed and used for the stem water content evaluation at each depth:

$$y = -2.6558E\text{-}09x^3 + 7.6682E\text{-}06x^2 - 6.3281E\text{-}03x + 1.6607E{+}00 \quad (8cm)$$
$$y = 4.4351E\text{-}08x^3 - 1.2451E\text{-}04x^2 + 1.1755E\text{-}01x - 3.7113E{+}01 \quad (9cm)$$
$$y = 2.8212E\text{-}23x^{7.2683E+00} \quad (10cm)$$
$$y = 1.5803E\text{-}05e^{9.2477E-03x} \quad (11cm).$$

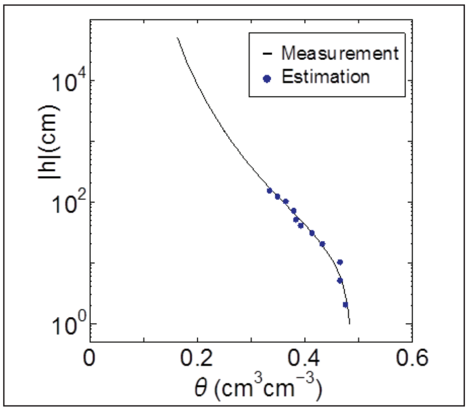

Figure 3: Soil retention curve.

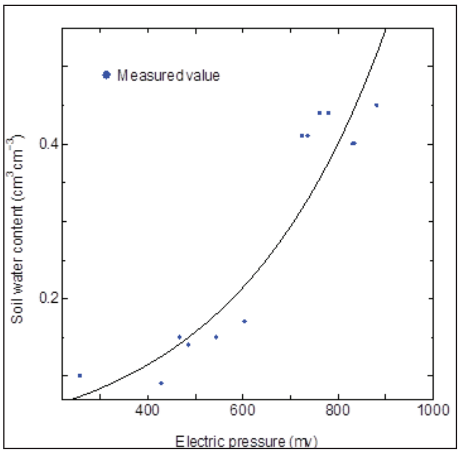

Figure 4: Calibration curve for soil water content.

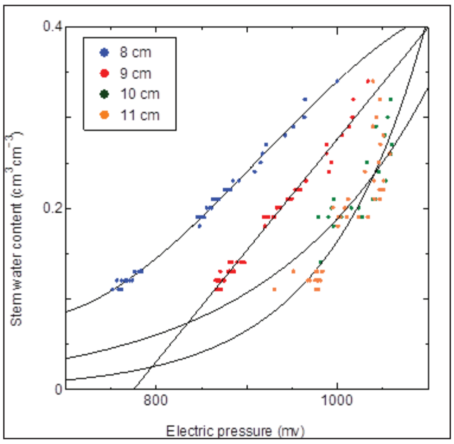

Figure 5: Calibration curve for stem water content.

Water status indicators

The measured average values of the soil water content (average of four depths and four trees for each treatment) from March to September are given in Fig. 6. The soil water trends for the irrigated and rainfed treatments were quite similar during spring. Both showed high water content, but it gradually decreased as summer approached.

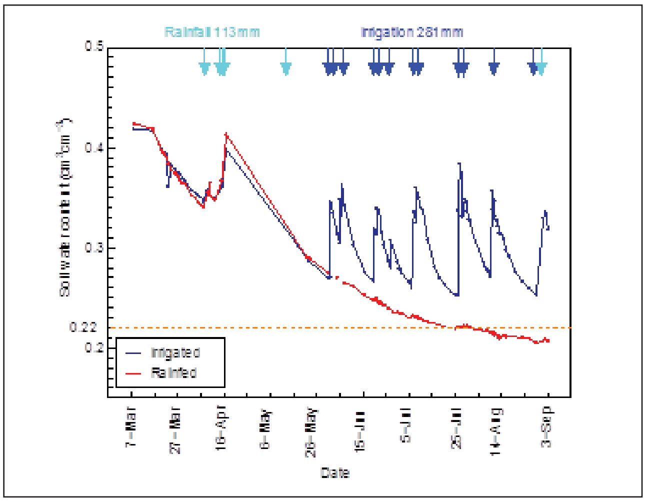

Figure 6: Soil water content of olive trees in irrigation and rainfed treatment.

Irrigation was started from June, and its effect clearly appeared with immediate increase in soil water content. After about ten days, the soil water decreased and reached the values of the rainfed treatment. The value of the rainfed treatment continued to decrease in the dry season because the rainfall was inadequate. The average soil water declined from the initial measured value (around 0.42) by 24% in the irrigated treatment (reaching about 0.32) and by 52% in the rainfed treatment (reaching about 0.2) that are close to the wilting point. Fig. 6 suggests that the soil water content in the irrigated treatment was maintained above this critical value and thus the trees did not encounter the water stress. But in the rainfed treatment the threshold value was reached around July 25, subjecting the trees to water stress.

Figure 7 shows the average stem water content from March to September. Irrigation and rainfed treatments showed similar trends during the rainy season (spring). The values reduced gradually as the summer season approached, and the trends started to change at the beginning of July. In the irrigated treatment, the stem water content was not immediately affected by the irrigation after the first application, but it increased gradually and later recorded higher values than in the rainfed treatment. The stem water content declined about 5% in the irrigated treatment (reaching 0.30) and about 19% in the rainfed treatment (reaching 0.26) from the average initial value (0.32).

The sap flow was measured from the beginning of July to September. In Figures 8 and 9, the measured inner (7.5 mm) and outer (22.5 mm) velocities of the irrigated and rainfed treatments are shown. Different trends between treatments were detected. In the irrigated treatment, higher sap flow velocity was also significantly affected by irrigation, declining until irrigation and increasing after that. The velocity of the rainfed treatment continued to steadily decrease until the end of the experiment. In general, the outer sap flow is higher than the inner one for both

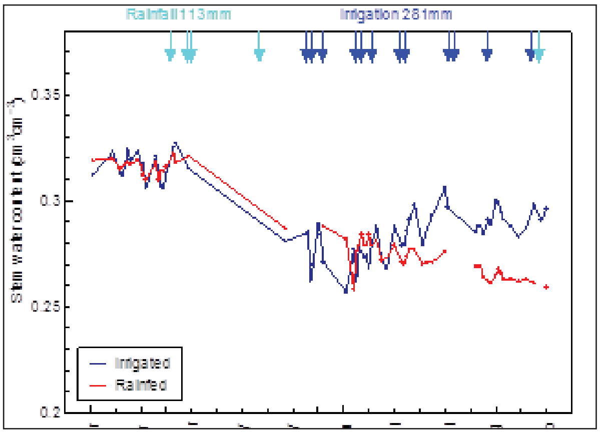

Figure 7: Stem water content of olive trees in irrigation and rainfed treatment.

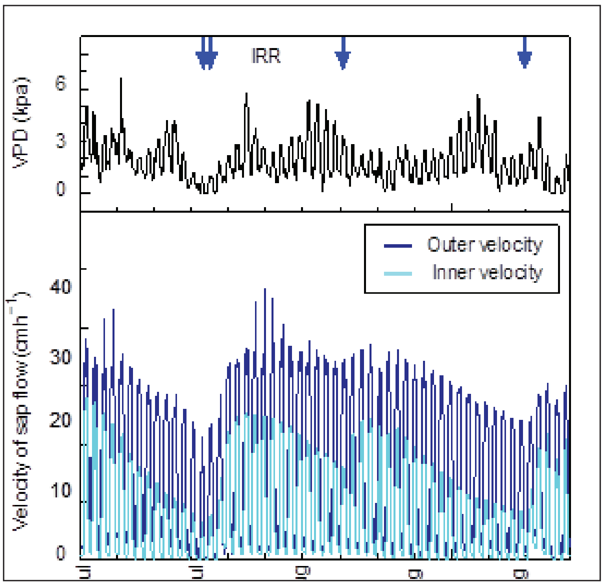

Figure 8: Velocity of sap flow of olive trees and VPD in irrigated treatment.

treatments. The inner sap flow seemed to be more affected by the water stress than the outer sap flow. The sap flow is strongly connected with VPD. The occurrence of water stress can sometimes be identified by comparing the sap flow with VPD. The sap flow has to increase with high VPD values if there are no water restrictions in the soil. For example, in Figure 8, the sap flow velocity seems to decrease when VPD is low. On the other hand, for rainfed treatment (Figure 9) the trend was quite independent with respect to VPD; because the plants were exposed to water stress, the stomata were closed, and transpiration was reduced to a minimum.

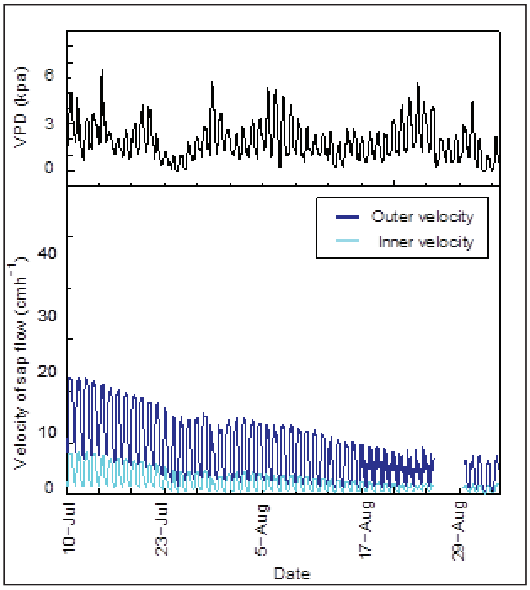

Figure 9: Velocity of sap flow of olive trees and VPD in rainfed treatment.

In Figure 10, a comparison of the average daily velocity of the sap flow for the irrigated and rainfed treatments is shown. There is a clear difference in the sap flow between treatments, and the rainfed trees were exposed to water stress at that time. At the beginning of July, the measured velocity in the irrigated treatment was twice as big as in the rainfed one. There was a gradual decline later, and sometimes the velocity of the irrigated one reached the velocity of the rainfed one, meaning that the irrigated trees had also experienced water stress.

The leaf conductance was measured from June to September (Figure11); the values were average of four trees for each treatment. A similar trend was detected for both treatments until July 10, and then the values gradually started to differ. The leaf conductance did not seem to get affected by a single irrigation application, although a clear overall effect of the soil water regime (as affected by irrigation) was detected.

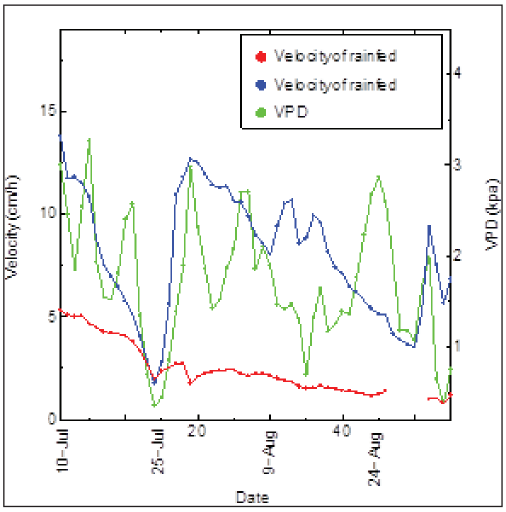

Figure 10: Daily velocity of sap flow of olive trees and VPD in irrigated and rainfed treatment.

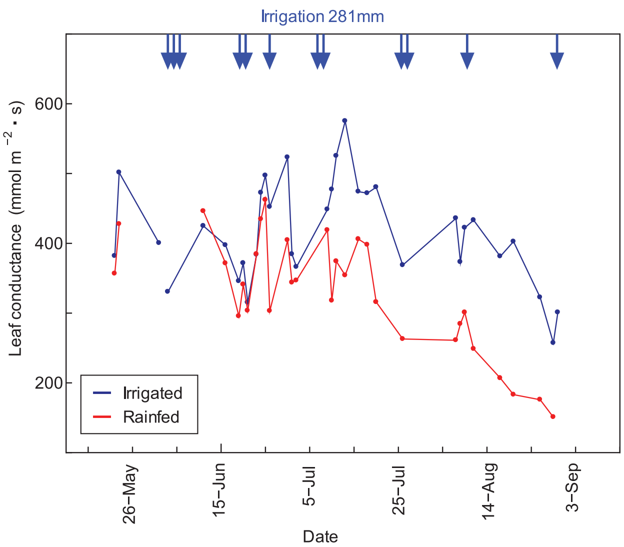

Figure 11: Daily leaf conductance in irrigated and rainfed treatment.

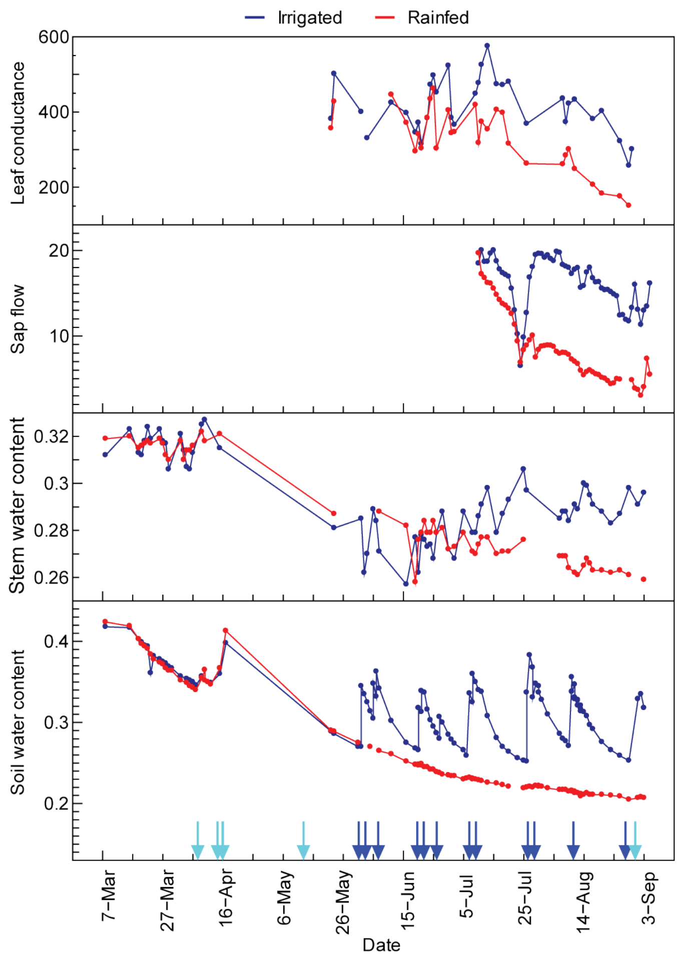

Figure 12: All indicators during experiment period.

We comprehensively assessed the irrigation effects on various water status indicators (Figure 12). The experimental period can be divided into three phases. The first phase was from March 7 to June 1, in which both the irrigated and the rainfed treatments had similar trends for all the measured indicators. In the second (up to July 9), irrigation started to affect the soil water content in the irrigated treatment. Finally, the condition of the trees also began to change in terms of both the stem water content and the leaf conductance, and a sort of third phase was detected from July 10 until the end of our experiment.

The differences in the tree stem water content and the stomatal conductance between the treatments started to increase, and the water stress probably started to seriously affect the rainfed trees. At this point, the soil water content in the rainfed treatment was 0.23 cm^3 cm^{-3}, which can be considered a sort of critical point for the olives in this field. It is very close to the threshold value of the soil water content for RAW (0.22), as calculated using the FAO 56 approach (Allen *et al*. 1998). After this point, all the plant water status indicators showed a clear trend in the reduction to minimal values. In addition, when the soil water content of the irrigated treatment reached this threshold, the sap flow also fell to values that resemble the rainfed ones.

Plant growth

There was no difference in the number of leaves between treatments (Table 2), but the differences became significant in the final weight of the leaves and the leaf area. The branches from the irrigated area also had a higher amount of bigger fruits. In contrast, the fruits from the rainfed treatment area were fewer and smaller. Thus, we detected a clear effect of the irrigation on both the canopy development and the fruit establishment.

Conclusion

Our experiment comprehensively investigated the response of olive trees to different soil water conditions by measuring various water status indicators: soil water content, tree stem water content, sap flow, and leaf conductance. All the plant water status indicators showed a clear trend of reduction to minimal values. According to our results, the differences in the physiological responses of the olive trees under irrigated and rainfed conditions can be evaluated by integrated observations of water movement in the soil-plant–atmosphere continuum. Indicators such as tree stem water content and sap flow can be effectively used to evaluate the occurrence of water stress in olives, and with additional data on soil water content, and/or the evaporative demand of the atmosphere the evaluation can further improve. The effectiveness of irrigation strategies to avoid water stress can also be confirmed by such indicators. Finally, these studies on plant-water relations are very useful for irrigation science and related applications, for example, to improve the reliability of prediction model and for parameter estimation (e.g., threshold values of RAW in the FAO I&D Paper 56).

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Modeling stomatal conductance of durum wheat (*Triticum durum)* in drylands by field experiments

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Abstract

Stomata play a very important role in preventing leaf surface from reaching excessive temperatures through the control of plant transpiration and its associated cooling effect. They thus have important function in adaptation of plants to drought-prone environments. This research aimed at 1) studying the variability and responsiveness of durum wheat (*Tricticum durum*) stomatal conductance (g_s) to change in the environmental factors and time, and 2) modeling g_s of durum wheat applying Jarvis model. An experiment was conducted in northern Syria, which has arid and semi-arid environment, involving four irrigation treatments (rainfed - 0 %, full irrigation -100 %, and two intermediate levels of 33 % and 66 % of full irrigation). The g_s was significantly affected by soil water content, and even the crop in full irrigation treatment experienced water stress before irrigation. In the rainfed treatment, g_s values were very small compared with other treatments. The performance of the model was evaluated by the nonlinear least squares method, and the simulated results were in good agreement with observations. Also sensitivity analysis was performed on parameters used in the model by running the model with different scenarios where the parameters were varied by ±20 % from the optimum value. The analysis showed that the model was mostly sensitive to the variations in soil water potential. On the other hand, the model was insensitive to variations in vapour pressure deficit (VPD) because of small range of VPD values in the study. These results suggest that identifying the parameter in the equation about soil water potential and measuring g_s in the wide range of VPD would improve the model.

Introduction

Since leaf stomata regulate the water-use efficiency of crop and energy partitioning into sensible and latent heat (Yu *et al.* 2004), the parameterization of stomatal conductance is essential in simulations of crop productivity and water-use efficiency in agricultural systems.

The stomatal conductance of leaves in vegetation canopies is an important variable that affects the exchange of water vapor, CO_2, and trace gases between vegetation and the atmosphere (Campbell 1998). Stomata play a crucial role in evapotranspiration (ET) and photosynthesis (Jarvis and McNaughton 1986). In semi-arid environments, such as northern Syria, water availability in the rainy season is crucial for the growth and survival of vegetation, and the stomatal control of water loss is less important for conserving water and using it at critical stages.

In arid and semi-arid areas, since water scarcity is a critical problem, efficient irrigation is essential through appropriate irrigation scheduling. Estimating the amount of ET is crucial for scheduling irrigation for effective water use. Transpiration is strongly affected by stomatal conductance (g_s), which indicates the degree of the stomata aperture and varies with changes in the environmental factors. Therefore, this study modeled the stomatal conductance of durum wheat (*Triticum durum*), which is a major crop cultivated in dry areas.

Stomatal conductance and models

Stomata play a key role in modulating the transpiration-driven water flow through the soil-plant-atmosphere continuum and determine the rate of soil water depletion. Stomata also play an important role in preventing leaf surfaces from reaching excessive temperatures by controlling the plant transpiration and its associated cooling effect. We must understand how stomata respond to environmental factors and optimize their responses.

In ecosystems, evapotranspiration is divided into evaporation from the soil surface and transpiration from plants, and transpiration regulated by stomata accounts for a large part of ET in the canopy. This also affects the distribution of the sensible and latent heat of radiation energy.

One parameter for analyzing water vapor and CO_2 flux between plant and atmosphere is stomatal conductance (g_s), which varies with the stomatal opening level and is sensitive to environmental factors. Modeling g_s based on a physiological mechanism has become important, and developing an estimation model has recently received much attention.

Various approaches to modeling g_s have been studied, including many different kinds of models. Among them, an environmental variable model is used widely, because it can connect with ET and photosynthetic models and estimates g_s using readily available micrometeorological data.

In the environmental variable models, g_s is the product of the response functions to individual environmental factors; each function is generally determined by boundary line analysis (Webb 1972; Chambers *et al.* 1985). The hypothesis behind this approach is that the response to each environmental factor is independent of others. Jarvis (1976) first proposed a model that integrates responses to PAR (photosynthetically active radiation), leaf temperature, VPD (vapor pressure deficit), CO_2 concentration, and leaf water potential. This model is now used widely.

Stomatal behavior under natural conditions depends on environmental factors (Jarvis 1976). In this study CO_2 concentration was not considered because it was not measured in this field experiment. PAR (Q), VPD (D), soil water potential (ψ), and leaf temperature (T) were adopted as parameters, and then we composed the following Jarvis type model:

$$g_s = g_{s\max} f(Q) f(T) f(D) f(\psi) \qquad (2.3.1)$$

$$g_{s\max} f(Q) = \frac{g_{s\max} Q}{Q + \frac{g_{s\max}}{a}} \qquad (2.3.2)$$

$$f(D) = 1 - b_1 D \qquad (2.3.3)$$

$$f(T) = \left(\frac{T - T_l}{T_o - T_l}\right)\left\{\left(\frac{T_h - T}{T_h - T_o}\right)^{\frac{T_h - T_o}{T_o - T_l}}\right\} \qquad (2.3.4)$$

$$f(\psi) = 1 - \frac{\psi_{\max} - \psi}{\psi_{\max} - c} \qquad (2.3.5),$$

where T_h is the maximum limit temperature (about 60˚C), T_1 is the minimum limit temperature, T_0 is the optimum temperature, ψ_{max} (-cm H_2O) is the soil water potential at the field capacity, and c is the soil water potential at the stomatal closure. We adopted Hanan and Prince's model (1997) as the function for the soil water potential.

The conditions for identifying the model's parameters are shown in Table1. The value of ψ must range from c to ψ_{max}. Value c was set to -30,000 cm H_2O, exceeding the wilting point that is usually around -15000 cm H_2O; this value is considered adequate because g_s can be measured near -30000 cm H_2O. The parameters were identified by the nonlinear least squares method.

Table 1: Range of model parameters

g_{max} =450
$0 < a \leqq 1$
$0 < b_1 < 5$
$5 \leqq T_l \leqq 10$
$10 < T_0 \leqq 25$
$40 \leqq T_h \leqq 50$
$\psi_{max} = -100$
$-30000 \leqq c \leqq -15000$

Assessing how the performance of model responds to perturbation in individual parameters is important, so that the results can be used to guide model parameter estimation. For this reason, we performed sensitivity analysis on the parameters used in our model. The relative sensitivety (*Sr*) (McCuen 1973) was given by the equation:

$$S_r = \frac{F_a - F_b}{X_a - X_b} \frac{X_b}{F_b} \qquad (2.4),$$

where X is a parameter and F is an evaluation function. Subscripts a and b express the condition before and after alternating the parameter. The root mean square error (RMSE) was used as the evaluation function.

We must identify eight parameters in this model. Each parameter depends on the function type used for independent variable expression. If the model's accuracy is only maintained by a constant term, the number of parameters can be reduced, and the utility will increase. The sensitivity was compared, perturbing each parameter ±20% from the optimum value.

Materials and method

The study was conducted at the Tel Hadya experimental station of the International Center for Agricultural Research in Dry Areas (ICARDA) near Aleppo in northern Syria. The site is representative of northern Syria's main cereal-growing region. Rainfall starts in October/November and extends to April/May with substantial variation within season and years and a long-term average of 330 mm. Temperatures also show considerable interannual differences. Figure 1 gives the data for the long-term weather conditions. The soil at Tel Hadya is fine, thermic, mixed, and mesic Calcixerollic Xerochrept (Ryan *et al.* 1997). The volumetric water content values at the field capacity and the wilting point were 0.52 $cm^3 cm^{-3}$ and 0.26 $cm^3 cm^{-3}$, respectively.

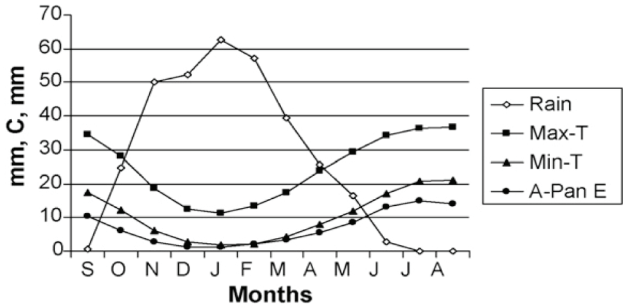

Figure 1: Long-term weather conditions of experimental location.

The experiment area consisted of 60, 10-m wide, 6.5-m long plots with a 1-m buffer between adjacent plots. Durum wheat (cv. 'Cham 5') was sown on December 10, 2010 in 0.175-m rows at a seed rate of 140 kg ha^{-1} in 6.5 m × 10 m long plots. The plots were arranged in a randomized complete block design with three replications of four moisture regimes, viz. rainfed (0%) and full irrigation (100%), and two intermediate levels, 33% and 66% of full irrigation. The nitrogen rate was 140 kg N ha^{-1} with applications of 80-kg N ha^{-1} before sowing and 60 kg N ha^{-1} during tilling. Phosphorus at 100kg ha^{-1} was applied at planting. The harvesting was done on June 7, 2011.

We collected global radiation, PAR, sunshine hours, air temperature, relative humidity (RH), wind speed, precipitation, and class-A pan evaporation data at the ICARDA Tel Hadya station near the experimental field. The VPD was calculated from the relative humidity and temperature values (Campbell 1997).The volumetric water content (θ) was measured with a neutron moisture probe (Didcot Instruments, Co. Ltd.). Prior to sowing, an aluminum access tube was inserted in the center of each plot at 180 cm or to the maximum possible depth where the soil depth was lower due to the presence of rocky or calcareous layers. We monitored the soil water content using a site-calibrated neutron probe at approximately weekly intervals, except during periods of wet soil conditions that prevented us from approaching the tubes. A total of 18 soil water profile measurements were taken during the season, every 15 cm in the soil profile (except for the soil's top 15 cm) to the bottom of the access tube. The soil water content in the top 15-cm layer was measured gravimetrically at the time of the measurements by the neutron probe. Surface soil samples were collected with a 10-cm auger. Fig. 2 shows the soil water retention curve.

The volumetric water content was converted to matric water potential using existing soil moisture retention curve (Ryan *et al.* 1997):

$$\theta = \begin{cases} -\dfrac{\log\psi - \log(2\times10^{6})}{19.62} & (\psi < -74) \\ 0.52 & (\psi \geq -74). \end{cases}$$

We used a drip irrigation system for the supplemental irrigation (SI). The soil available water in the top 60-cm depth in the 100% water treatment was used as the basis to apply the required irrigation water for different treatments. Water was applied when the soil water dropped to 50% of the maximum soil available water. Irrigation of the intermediate water regime plots occurred on the same day as the fully irrigated plots, but the application depth was reduced to 33 and 66%

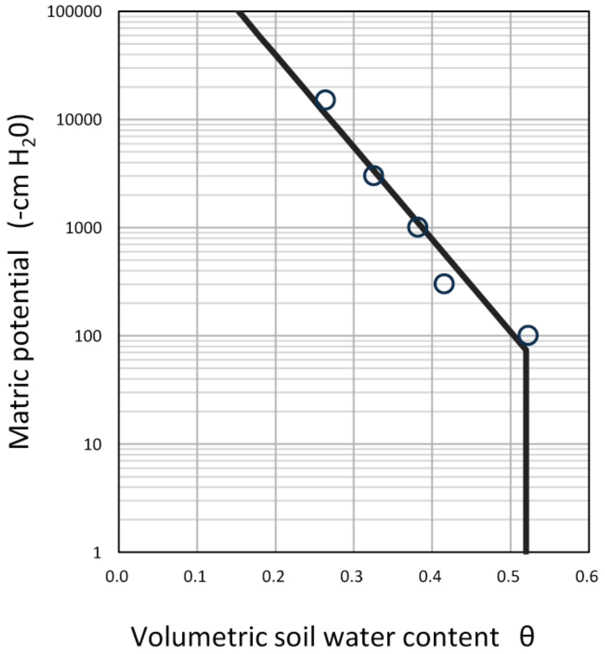

Figure 2: Soil water retention curve. Marks are actual measured value, and solid line is based on above equation. θ at field capacity and the wilting point are 0.52 and 0.26, respectively.

of the full irrigation. We monitored the irrigation amounts using flow meters at each treatment. The irrigation season lasted from March 22 to May 10, for a total of four irrigations. The full irrigation amounts were 80 mm each in the first three and 60 mm in the fourth irrigation event.

Stomatal conductance measurements were made with a transient porometer (Delta-T Devices Ltd.) of the abaxial surface of the flag leaf five times in each plot from March when the dry season started to the beginning of May. Flag leaves were selected randomly from each plot. The leaf temperature was also measured at the same time.

During the growing season in April, the crop height, the leaf area index (LAI), and the dry matter of the crop's aerial parts were measured weekly. The dry matter of stem, leaf, and spike were measured at the anthesis, grain filling, and dough stages. We also quantified the length of the growth stages, the yield, and the yield components.

Results and discussion

The amount of precipitation was 209 mm during the experimental period, 30% of which occurred in December, 2010. From the middle of March to the beginning of April, precipitation was clearly inadequate for rain-fed cultivation. We needed to irrigate during this period.

We measured the soil moisture content (θ) with 30-cm deep increments from the soil surface to 180-cm depths. The θ of the top 30-cm layer changed dramatically; however, this change became smaller with increasing depth, and θ changed little at 150-180 cm layers.

Before starting irrigation, θ increased slightly at the 30-60 cm layers from the end of January to the beginning of February; however, the effect of the precipitation only reached the top 30-cm layer. In the 100% irrigation treatment, the first three 80-mm irrigations affected the soil moisture content to the 120-cm depth, and the fourth irrigation (60 mm) only had an effect to the 90-cm depth. In the 66% treatment, the first three, 53.6-mm irrigations affected the soil moisture to the 90-cm depth, and there was no effect of the fourth irrigation (40.2 mm) at 60-90 cm depths. In the 33% treatment, soil θ increased slightly at the 30-60 cm layer after every irrigation (1^{st} to 3^{rd} irrigation: 26.4 mm, 4^{th} irrigation: 19.8 mm), so the irrigation water only infiltrated near the top 30-cm layer. In the 0% treatment, every soil layer at each depth had little change, except the top layer.

The diurnal changes of g_s measured on April 7 and 10, 2011 are shown in Figure 3**.** We measured g_s three to four times a day. The changes did not have common distinctive trends, and the effect of the irrigation treatment was strong. In the 0% treatment, g_s was very small. It ranged from 4 to 15 mmol m^{-2} s^{-1}. It was impossible to measure g_s in the afternoon on April 10 because the stomata closed. We found few differences between the 100% and 66% treatments; g_s was smaller in the 33% treatment. Except for the 0% treatment, the g_s measured on April 10 changed in a similar way.

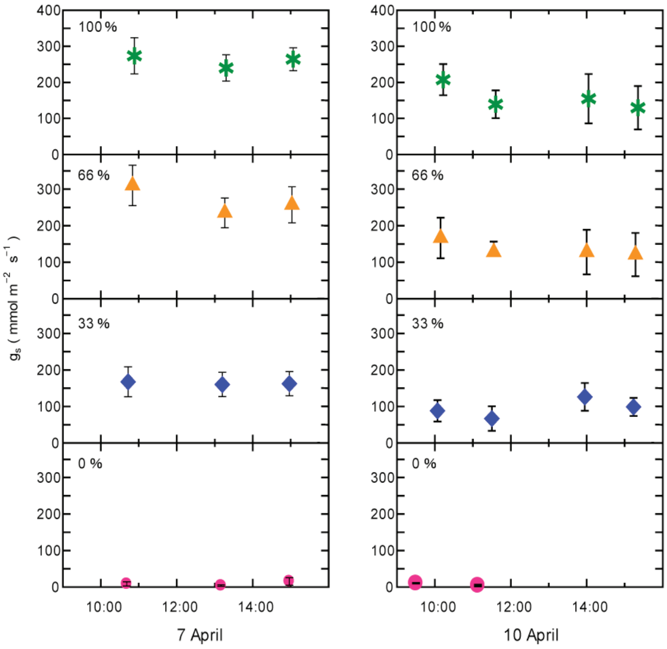

Figure 3: Diurnal changes in gs on April 7 and 10, 2011.

The long-term changes in the diurnal stomatal conductance and the amount of irrigation and precipitation from March to the beginning of May in 2011 are given in Figure 4. In the case of g_s, which was measured three times or four times a day, we averaged the values because the diurnal change was not confirmed. After starting irrigation on March 22, in the 100% and 66% treatments, g_s was nearly equal, but in the 33% treatment it was smaller, and in the 0% treatment it was extremely low. During the measurement period, we irrigated on March 22 and April 5 and 19 with 80 mm (100% treatment) of water. The g_s after irrigation was higher than that before irrigation in every treatment that received irrigation. This means that, before irrigation, even the crop in the 100% treatment, which received sufficient amount of water, experienced water stress.

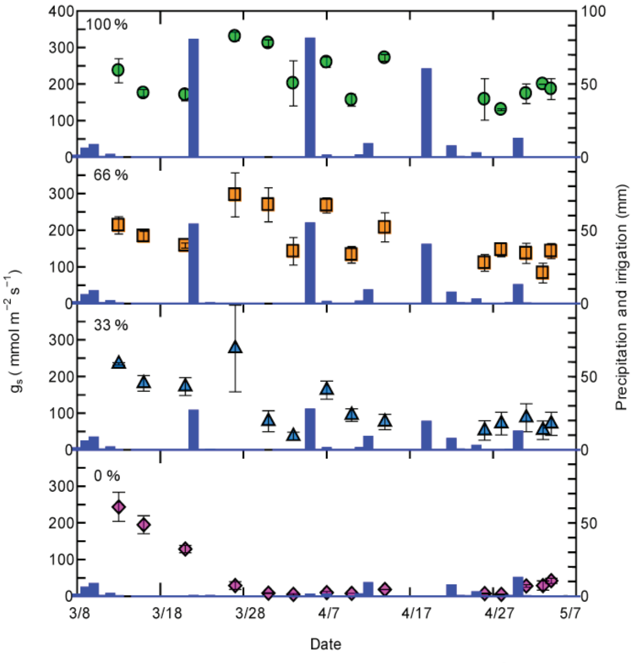

Figure 4: Long-term changes in gs and amount of precipitation and irrigation. Blue bars are amount of irrigation and precipitation. Marks are g_s.

The relationships between g_s and the environmental factors (PAR, VPD, leaf temperature, and *θ*) for each treatment and their totals were studied. The total data include the data that were measured before irrigation was started.

PAR was the most influential factor affecting g_s. In the 100% treatment, g_s tended to increase with an increase in PAR ($R^2 = 0.37$), but there was no relation in the other treatments. Oue (2003) expressed the relationship between g_s and PAR as a non-equilateral hyperbola, which is often applied to the relationship between PAR and the photosynthesis rate. Willmer and Fricker (1996) and Ishihara *et al*. (1972) concluded that it took more than 10 minutes for stomata to respond to significant changes of light environment, and therefore such an insensitive response to the light is another explanation of the poor correlation.

As for VPD and g_s, in the 100% and 66% treatments, even though g_s demonstrated an upward trend to VPD, no particular relationship was obtained. Sato *et al.* (2006) expressed the relationship between the g_s of wheat and VPD as a hyperbolic curve, and Patane (2010) expressed it as an exponential curve in the case of processing tomato. Under a no water stress condition, g_s increased below 2.8 kPa but decreased above 2.8 kPa. In Patane's experiment, the maximum VPD was 2.5 - 2.9 kPa, so VPD's narrow range was not able to express relationship between g_s and VPD.

Generally, leaf or air temperature correlates highly with g_s. The stomatal aperture reaches a maximum at 30 - 35°C in many kinds of plants and becomes smaller when the temperature is above or below that. However, such relationships remained unrecognized in our study.

The relationship between the volumetric soil water content (θ) and g_s was studied. In each treatment, the correlation and the gradient of the approximation were completely different;

however, their totals had a strong correlation. When θ was under 0.26, g_s decreased drastically, and when θ was over 0.26, g_s did not vary significantly. This indicates that the soil water content became a large limiting factor for g_s when soil water content fell below θ= 0.26, but above it, other environmental factors affected g_s.

For every treatment, we modeled g_s by optimizing the parameters by the nonlinear least squares method. The estimated g_s was obtained by substituting the environmental factors and their parameters into the equations mentioned earlier. The estimated g_s agreed well with the observed g_s (Fig. 5). Our model expressed the effect of soil moisture that was a limiting factor for g_s in the dry soil moisture condition. The root mean square error (RMSE) was 41.8 mmol m^{-2} s^{-1}.

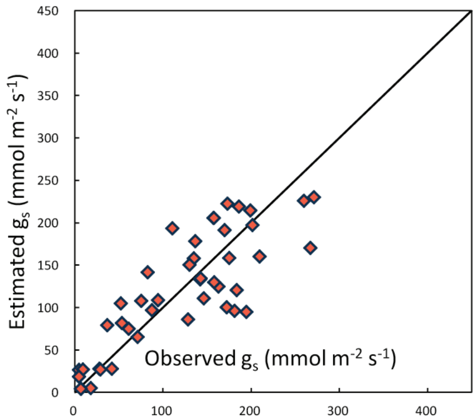

Figure 5: Comparison of estimated and observed g_s of every treatment. RSME = 41.8 mmol m^{-2} s^{-1}.

Next, in the 100% treatment, where there was little soil moisture stress, gs was also modeled by the optimizing factors. Parameters were optimized in the same way. The parameters a and T0 were only slightly changed (Table 3) compared with the model which optimized parameters using gs in every treatment (Table 2). The estimated and observed gs in the 100% treatment showed excellent match (Fig. 6). Our model thus estimated gs with good accuracy. The RMSE was 41.6 mmol m-2 s-1. The gs in the 100% treatment did not change drastically with the soil moisture, so the model also reflected the effects of other environmental factors.

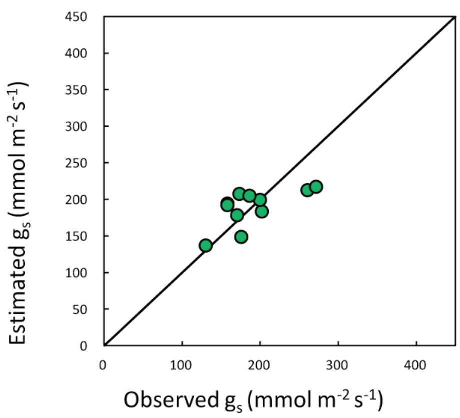

Figure 6: Comparison of observed and estimated g_s in 100% treatment. RSME = 41.6 mmol m^{-2} s^{-1}.

Table 2: Optimized parameters of every treatment

g_{max}	a	b_1	T_l	T_0	T_h	ψ_{max}	c
450	0.493	0.001	10	24.12	50.00	-100	-30000

To examine whether these parameters in the 100% treatment (Table 3) are applicable for every treatment, we estimated the g_s for all treatments by substituting the parameters and the factors into our model. The model tended to estimate g_s slightly lower than the observed g_s (Fig. **7)** but the RMSE was 42.6 mmol $m^{-2}s^{-1}$, which is slightly different compared with the two previous models. Therefore, the model using only the 100% treatment data, where g_s was affected by slight water stress, estimated g_s with high accuracy.

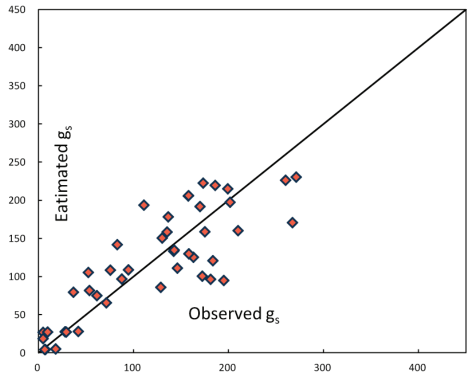

Figure 7: Comparison of observed g_s and estimated g_s of every treatment; RSME = 42.6 mmol m^{-2} s^{-1}.

After recognizing that g_s was obviously affected by the soil water content, we examined how the model responded to the soil water content. The relationship between θ and g_s is shown in Figure 8. The estimated g_s under a fixed condition approximately corresponded to the observed g_s, where the effect of θ was well expressed. Our model, which includes and considers the effect of θ, estimates g_s with a high degree of accuracy. However, it does not consider the very wet soil moisture condition. If that condition occurs, plants might suffer from such wet damage as root rot, and g_s would be affected. Our model must be improved in this regard.

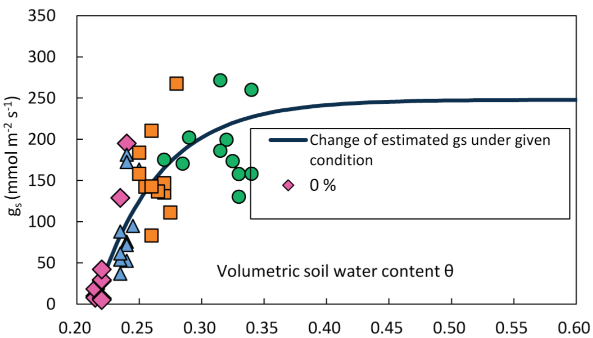

Figure 8: Observed and estimated g_s under given condition. Solid line is change of estimated g_s under averaged environmental factors at each treatment without θ.

Table 3: Optimized parameters of 100% treatment

g_{max}	a	b_1	T_l	T_0	T_h	ψ_{max}	c
450	0.430	0.001	10	23.61	50.00	-100	-30000

The sensitivity analysis result (Table 4) showed that our model was sensitive to *a*. The value of $f_q(Q)$ became smaller with a low value of *a*, showing the effect of PAR on the estimation of the g_s decreased. Since PAR is an influential factor on the response of g_s, g_s is estimated lower when *a* is small, and $f_q(Q)$ excessively affected g_s and suppressed other factors when *a* was high.

On the other hand, our model was unresponsive to b_1, indicating the possibility of eliminating $f_d(D)$. However, in this experiment, the small VPD range (1-3 kPa) probably explains such unresponsiveness. In a similar experiment (Sato *et al.* 2006), g_s did not vary notably in a VPD range of 1-3 kPa, but it decreased over 3 kPa. An extensive range of VPD is required for a higher precision model.

Table 4: Relative sensitivity of parameters, gsmax, a, b1, Tl, T0, Th, ψmax, c on RMSE

Parameters	Identified value	Perturbation (%)	S_r (RMSE)
g_{smax}	450	-20	-0.1702
		+20	0.2527
a	0.493	-20	-0.1205
		+20	-0.0857
b_1	0.001	-20	0.0074
		+20	0.0018
T_l	10	-20	-0.0024
		+20	-0.0120
T_0	24.12	-20	-0.3649
		+20	0.0752
T_h	50.00	-20	0.0918
		+20	-0.1135
ψ_{max}	-100	-20	-0.0811
		+20	-0.1212
c	-30000	-20	-0.9931
		+20	0.4185

As for $f_\psi(\psi)$, our model was more responsive to *c* than to ψ_{max}. This means that $f_\psi(\psi)$ doesn't vary greatly under high soil water content conditions because most stomata open and allow transpiration; but $f_\psi(\psi)$ undergoes a major change in low soil water conditions because stomata start closing themselves. Actually we found little difference of g_s between the 100% and 66% treatments under the same conditions, but in the other low water treatments, g_s fell drastically. In arid regions, since soil water content easily decreases, we must consider and identify ψ_{max} and *c*.

These results suggest the possibility of eliminating fd(D) from the model function. We optimized the parameters without b1, and the result showed the optimized parameters were almost the same and the RMSE was 41.8 mmol m-2 s-1, reaffirming that fd(D) had little effect on this model.

Conclusion

This work modeled the g_s of durum wheat (*Triticum durum*), which is directly related to the amount of transpiration that is important for effective irrigation scheduling in dry areas. The observed g_s was assumed to strongly correlate with each environmental factor. However, we only recognized some tendencies between g_s and environmental factors and obtained no decisive relation, except the soil water content, which considerably affected g_s. Despite the low correlations of other factors, however, after identifying the parameters and modeling g_s by a Jarvis type model using PAR, VPD, leaf temperature, and soil water potential, the estimated g_s agreed well with the observed g_s. Also, as a result of a sensitivity analysis, our model was especially sensitive to c in the soil water potential function and insensitive to b_1 in the VPD function. Optimizing without b_1 and estimating g_s with these parameters caused little difference compared with our model that considered b_1. For b_1, this result reflected the narrow range of the measured VPD, suggesting that identifying parameter c and measuring g_s in a wide VPD range would improve the model. Moreover, this model requires leaf temperature, which is not as readily available as general meteorological data.

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Theme 8
Arid lands communities, their indigenous knowledge and heritage, and socio-economic studies

Economic evaluation of regional water supply policy in Zhangye, China

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Abstract

Zhangye, north China, is facing serious water shortages because of the increase in the local population and development of irrigated agriculture. The main sources of water are the Hei River and groundwater, both of which are in short supply. The shortage has prompted the local government to implement water saving policies, which are influencing not only the quantity of water used but also Zhangye's economy as a whole. This research thus analyzes the economic impacts of the current water saving policies by using SAM (Social Accounting Matrix) and CGE (Computable General Equilibrium) models. In the first scenario, we assessed the impact of doubling the surface water price and found that the amount of surface water decreases by 7% of the total surface water input, while the amount of groundwater increases by 84% of the total groundwater input. This clearly is an inefficient scenario, because the loss of EV per yuan of surface water savings is 14.58 yuan. In scenario 2, we analyzed the impact of two groundwater pricing plans and found that in order to control the groundwater input, the groundwater price should be relatively low in primary industries and higher in other industries.

Introduction

The Hei River Basin in the north of China, including the city of Zhangye, is suffering from serious water shortages in terms of both surface water and groundwater. Therefore, the local government has implemented water pricing policy reforms to restrict water usage. However, these reforms have not only reduced domestic water use but also affected water use by local businesses, thereby influencing Zhangye's economy as a whole. The present study analyzes the economic impacts of these water price reforms using Social Accounting Matrix (SAM) and Computable General Equilibrium (CGE) models.

Structure of the SAM

In the SAM, we consider water use production factors in addition to labor and capital. In this study, this model thus employs 10 main activities and commodities: agriculture, forestry, livestock, fishery, agriculture service, mining, manufacturing, electricity, construction, and others. Moreover, water resources are divided into the surface water and groundwater used by enterprises to produce their goods and services.

Dividing the water sector according to water resources needs data on annual water usage by industrial sector, which were provided by the Zhangye Water Conservancy Bureau. However, these data need to be transformed before being input into the SAM, because their industrial classification (i.e., primary, secondary, tertiary) is different from that in the SAM. Therefore, both water inputs are calculated as shown in Table 1. The first row is the industry classification; AG, FO, LI, FI, AS, MI, MA, EL, CO, and OT represent agriculture, forestry, livestock, fishery, agriculture services, mining, manufacturing, electricity, construction, and others, respectively. The second row shows the data on water use derived from the Zhangye Yearbook (2007). The third row is the sum of previous water use for the primary, secondary, and tertiary industries. The fourth row is the rate of water input by industry. The fifth and sixth rows are data on groundwater and surface water usage supplied by the Water Conservancy Bureau (2011) by industry. The last row represents estimated water usage calculated by multiplying the fifth and sixth columns by the fourth column.

Finally, we create data for inputting into SAM by multiplying the estimated data in the last column by water prices. Surface water prices are 0.071 yuan/m^3 for primary sectors, 1.6 yuan/m^3 for secondary sectors (construction is 2.0 yuan/m^3), and 1.6 yuan/m^3 for tertiary sectors, while groundwater prices are 0.01 yuan/m^3 uniformly. In this research, we make a number of assumptions to formulate SAM : 1) The water authority collects income from the use of water resources and capital; 2) The income is transferred to the local government in order to fund future investment; 3) All the data in this SAM (excluding data on trade with the rest of the world - ROW hereafter) relate to Zhangye; 4) Households do not use water resources directly; 5) All water resources are consumed by industry; and 6) Trade in water resources with the ROW is zero.

Table 1: Calculation of water resource inputs

<table>
<tr><td colspan="2"></td><td>AG</td><td>LI</td><td>FO</td><td>FI</td><td>AS</td><td>MI</td><td>MA</td><td>EL</td><td>CO</td><td>OT</td></tr>
<tr><td>Year Book (2007)</td><td>Water Use (million m3)</td><td>2,171</td><td>59</td><td>19</td><td>0</td><td>0</td><td>2</td><td>36</td><td>6</td><td>6</td><td>4</td></tr>
<tr><td colspan="2">Sum of Water Use in 3 Classifications (million m3)</td><td colspan="5">2,249</td><td colspan="4">50</td><td>4</td></tr>
<tr><td colspan="2">Rate of Water Input</td><td>96.5%</td><td>2.6%</td><td>0.9%</td><td>0</td><td>0</td><td>4.3%</td><td>72.3%</td><td>12.2%</td><td>11.3%</td><td>100.0%</td></tr>
<tr><td rowspan="2">Data Is Supplied by Water Conservancy Bureau (2011)</td><td>Hei River Water Use (million m3)</td><td colspan="5">1, 612</td><td colspan="4">8</td><td>17</td></tr>
<tr><td>Ground Water Use (million m3)</td><td colspan="5">487</td><td colspan="4">49</td><td>47</td></tr>
<tr><td rowspan="2">Estimated Data</td><td>Hei river water (million m3)</td><td>1,556.0</td><td>42.1</td><td>13.8</td><td>0</td><td>0</td><td>0.3</td><td>5.5</td><td>0.9</td><td>0.9</td><td>16.9</td></tr>
<tr><td>ground water (million m3)</td><td>470.4</td><td>12.7</td><td>4.2</td><td>0</td><td>0</td><td>2.1</td><td>35.6</td><td>6.0</td><td>5.5</td><td>47.0</td></tr>
</table>

Structure of the CGE Model

This model aimed to assess how the water price reforms have influenced economic activity. The basic structure is similar to the study of Hosoe *et al.* (2004). To simplify the model, the following assumptions were made: 1) In the social economy, 10 kinds of goods exist as well as typical industries; 2) In the economy, a representative household, government, water authority, and investor exist; 3) The commodities produced in Zhangye and those produced in the ROW are different (Armington's assumption); 4) The factor markets of production (value-added) are composed of labor, capital, and water. Further, these markets are closed in the economy, and there is no outflow to the outside or inflow from the outside; and 5) All the markets except that for water operate under perfect competition and at the long-run equilibrium. Figure 1 shows the structure of the CGE model.

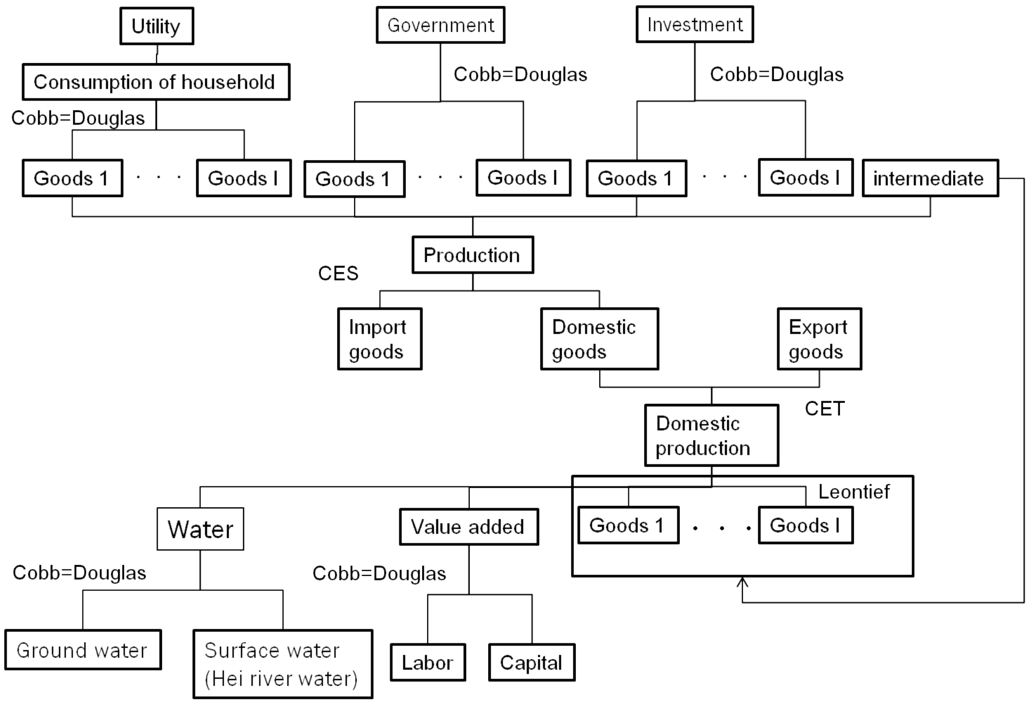

Figure 1: Structure of the CGE model.

Household activity

Households control their demand in order to maximize their utility under the budget constraint condition. Households hold the production factors of labor and capital. Moreover, they obtain income from factor markets as well as from transfers from the government and the ROW. With this income, households consume goods, pay income tax, and make savings. The utility function of households is expressed using a Cobb–Douglas function.

Investment activity

The income of the investment sector comprises savings from the ROW, households, and the water authority as well as disinvestment by the government. This income is used to pay investment tax and to invest into each industry. The amount of investment into each industry is decided by the cost minimization approach, which follows a Cobb–Douglas function.

Government activity

Government income comprises the payment of value-added tax, income tax from households, and tax from the water authority. This income is used to consume goods, transfer income to households, and disinvestment. The amount of goods consumed by the government is decided by the cost minimization approach, which again follows a Cobb–Douglas function.

Water Authority activity

The income of the water authority comes from supplying water to each industry. This income is then transferred to the government or saved.

Producer activity

A producer produces goods and services under the constraint of production techniques and aims to maximize profits. The producer would put in a constant level of an intermediate commodity, a value-added goods, and total water, and produce goods under the Leontief function. The value-added goods are then sadded to labor and capital in a Cobb–Douglas function. The total water comprises groundwater and surface water. However, there is fixed cost for groundwater. Therefore, the current price of groundwater is cheaper than that of surface water. All prices are decided by the Zhangye city government. Based on this model, groundwater use expands until the correlation of the amount of surface water use and groundwater use is reversed if there is substitution between these water resources. In other words, this cost covers the difference between groundwater use and surface water use, which is built into the CGE model as a fixed cost. In this model, it is further assumed that this fixed cost is borne by society because it becomes a loss of profit for each firm, which leads to a decline in the production of goods and services.

Trade with ROW

The total goods produced in the region are divided into domestic and export use categories using the CET function. Domestic goods are then added to imports using the CES function form. These goods are consumed by households, the government, investment, and intermediate inputs. Moreover, most parameters in the CGE model are calculated by calibration. However, the elasticities of substitution and transformation used in the CES and CET functions cannot be obtained by calibration. In this research, the elasticities of substitution and transformation are thus set based on the study presented by Okuda (2005): agriculture, forestry, livestock, fishery, and agriculture services are 4.4, mining is 4.2, manufacturing is 5.0, construction is 3.8, electricity is 3.7, and others are 3.2.

Definition of welfare

The measurement of policy impacts should also calculate the change in social welfare. In this analysis, we use the variable “household utility” to measure social welfare. Under the general equilibrium framework, we can use household utility in order to analyze the impact on the whole of society because firm profits ultimately flow back to households. However, this variable cannot show the degree of difference because it has an ordinal character. Therefore, difference in household utility is calculated using the equivalent variation (EV) approach, which compares utility before and after implementation at the fixed price before implementation.

Scenario analysis

The empirical analyses presented in this section comprise analyses for two scenarios.

Scenario 1 analyzes the case that the surface water price doubles, showing the degree to which groundwater increases as a result and how this price change affects Zhangye’s economy. In scenario 2, we analyze the economic impacts of two plans under the groundwater price reforms in order to examine which plan is better. Under plan 1, the price in primary industries (agriculture, forestry, livestock, fishery, and agriculture services) is doubled, while that in other industries (mining, manufacturing, electricity, construction, others) is increased by 1.5 times. Under plan 2, the price in primary industries is increased by 1.5 times, while that in other industries is doubled.

Result of scenario 1

Figures 2 and 3 respectively show the change in the surface water and groundwater inputs by industry. The surface water input (Fig. 2) increases in the livestock, mining, and construction sectors and decreases in the other industries. The groundwater input (Fig. 3) increases in all industries. The total change in the surface water input is -1.08×10^{1} million yuan (-7.01% of the total surface water input), while that in the groundwater input is 4.93 million yuan (84.43% of the total groundwater input). The amount of the surface water input in agriculture decreases greatly, whereas the rate of change in groundwater inputs are similar in value because of the substitution from surface water to groundwater. The increases in groundwater price make agriculture, which needs a large quantity of water, use much less surface water, while in the livestock and mining sectors, which need less water, only slight increases in the amount of surface water are noted.

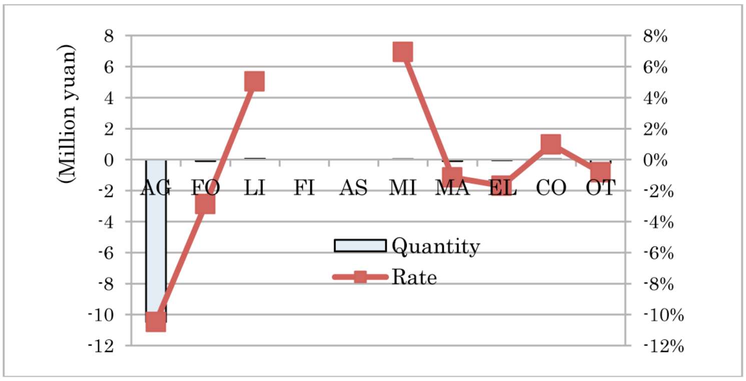

Figure 2: Change in the surface water input in Scenario 1.

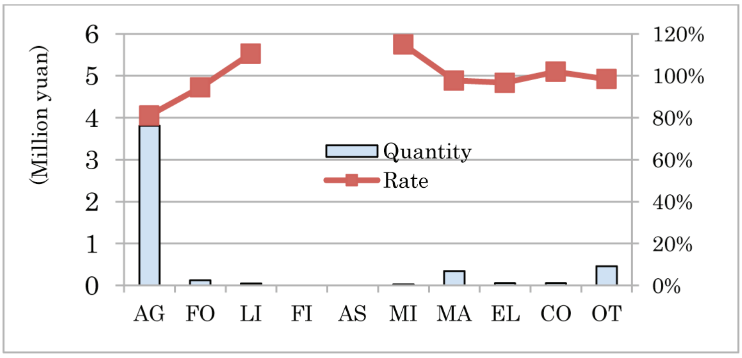

Figure 3: Change in the groundwater input in Scenario 1.

Figure 4 shows that production in the agriculture sector decreases, while that in livestock and mining increases to a much greater degree. According to Figure 5, production in agriculture decreases because of the rise in surface water price. This figure also shows that production in livestock and mining increases by using the labor and capital available following the decrease in agricultural production. The total change in the value of production is 1.31×10^{2} million yuan (0.43% of the total value). Moreover, other industries that require less water input are able to input labor and capital and thus decrease their supplier prices when agriculture and forestry, which need large water resources, raise their prices by increasing production costs. Similarly, the consumer price also changes in line with changes in the supplier price.

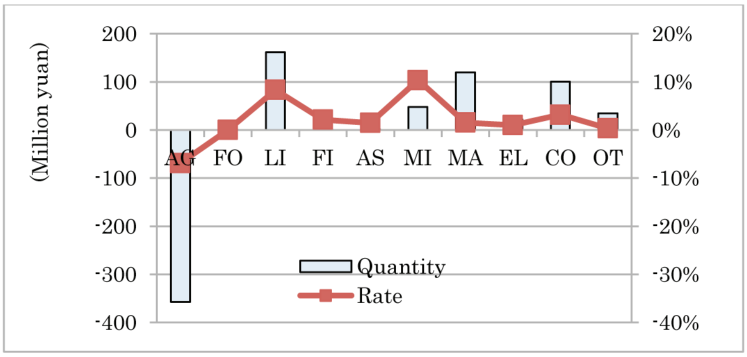

Figure 4: Change in the value of production in Scenario 1.

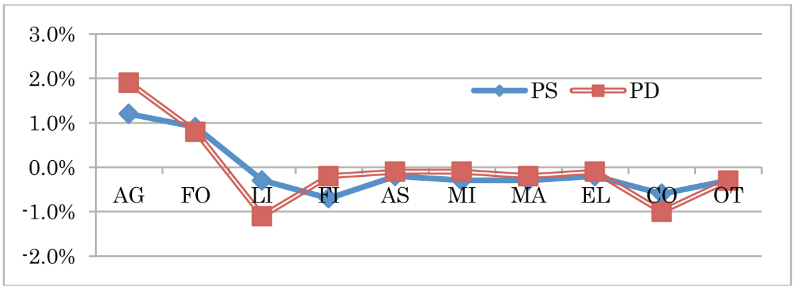

Figure 5: Change in the supplier and consumer's prices in Scenario 1

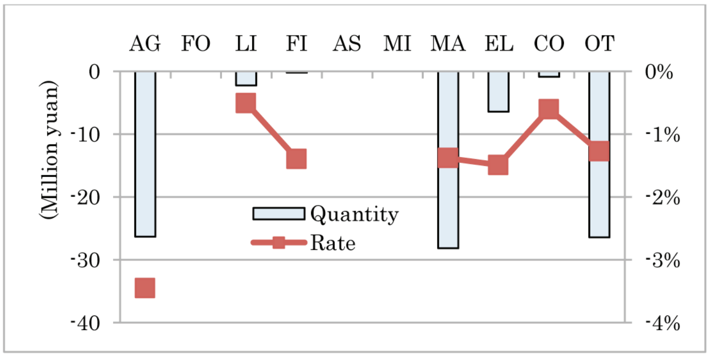

Figure 6: Change in household demand in Scenario 1.

Figure 6 shows the change in household demand for each good, Figure 7 the change in investment for each industry, and Figure 8 the change in intermediate input. We can see that the government only buys "other" goods (demand increases by 7.95 million yuan), while household demand decreases for all classes of goods because of a decline in household income (Fig. 6). By contrast, investment into all industries excluding agriculture increases (Fig. 7), while intermediate inputs for all classes of goods also rise (Fig. 8) owing to growing income levels. The quantity of intermediate input increases because this is decided only by a change in production and it does not depend on the price reforms. However, household demand and investment in agriculture decrease because the consumer price of agriculture greatly increases.

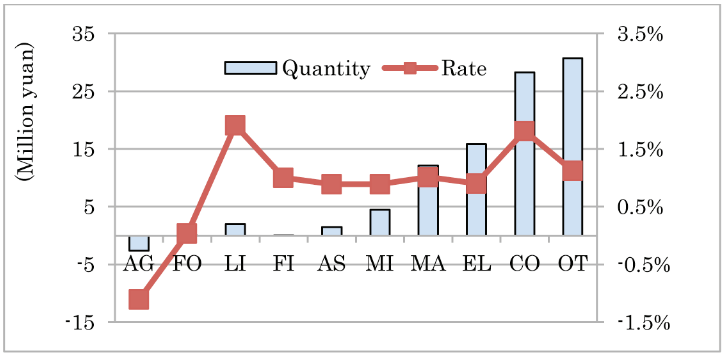

Figure 7: Change in investment in Scenario 1.

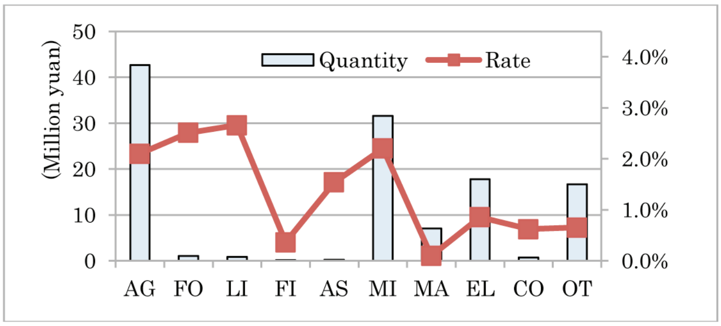

Figure 8: Change in intermediate inputs in Scenario 1.

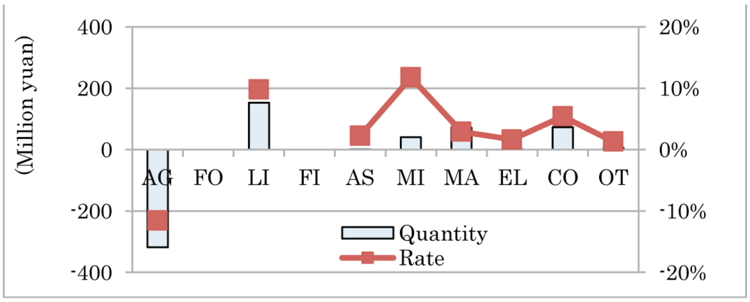

Figure 9: Change in exports in Scenario 1.

Figure 9, which shows the change in exports for each good, highlights that exports in the agriculture sector decrease, while those in livestock and mining increase. The reason for the decrease in agriculture is the decline in the profit of exports because the producer price has exceeded the export price. By contrast, exports in livestock and mining have risen owing to the higher export price and lower domestic market price.

In terms of imports, Figure 10 shows that imports in the agriculture sector have increased greatly because the domestic consumer price (including investments, the government, and intermediate demand) has exceeded the import price. In particular, imports in agriculture have increased because the surface water price reforms have greatly increased the degree of dependence on imports. Moreover, the reason for the difference in the supplier price and the consumer price in Figure 5 is trade with the ROW.

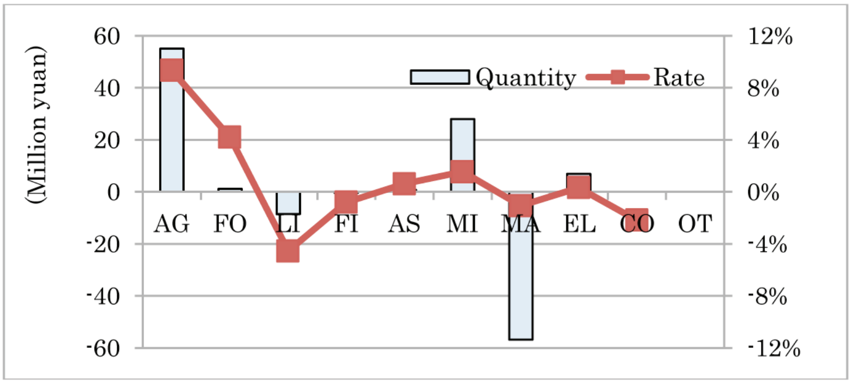

Figure 10: Change in imports in Scenario 1.

In summary, the EV loss is 1.57×10^2 million yuan, while the loss of EV per yuan of surface water savings is 14.58 yuan. Therefore, doubling the current surface water price in all industries through the surface water pricing reforms has created inefficiency, because the loss of benefit is more than the surface water savings.

Result of scenario 2

Figures 11 and 12 show the changes in groundwater and surface water inputs by industry. Quantity 1 and 2 mean the amount of change in plans 1 and 2, while Rate 1 and 2 mean the rate of change in plans 1 and 2, respectively. The change in the groundwater input in the overall industry decreases because all groundwater prices rise by more than the initial price under both price plans (Fig. 11). Further, the impact of the groundwater input under plan 1 is larger than that under plan 2. Figure 12 illustrates that the groundwater price reforms also influence surface water and that this influence is larger in enterprises that bear higher groundwater prices, as surface water and groundwater are substitutes. Therefore, groundwater is substituted more in primary industries under plan 1 but more in secondary and tertiary industries under plan 2.

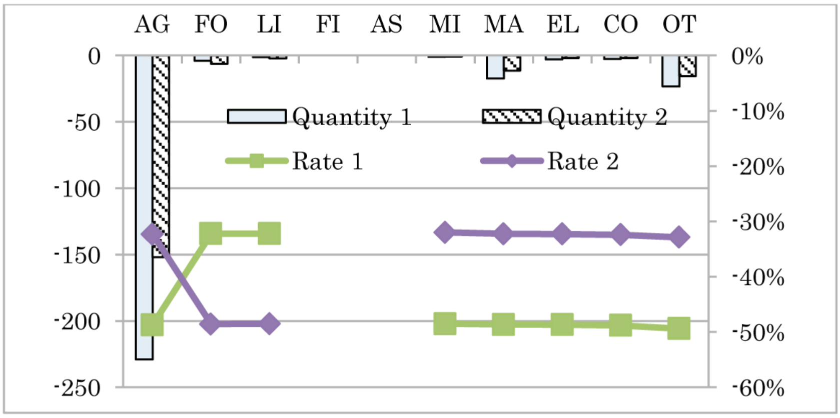

Figure 11: Change in the groundwater input in Scenario 2.

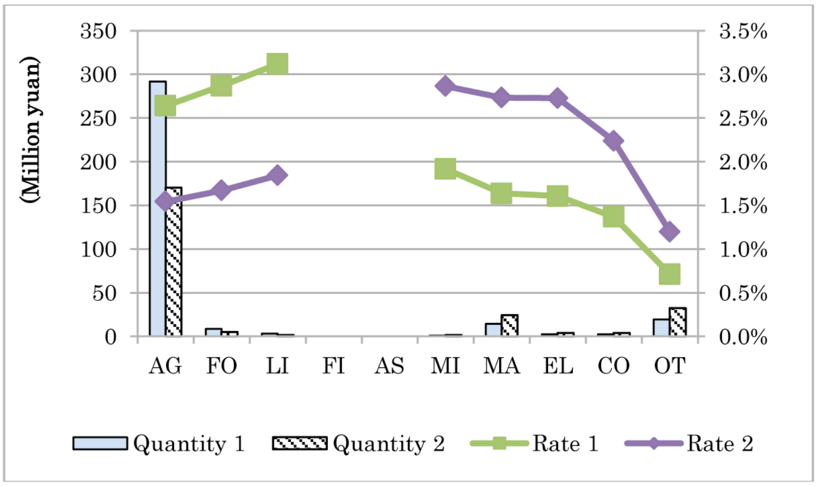

Figure 12: Change in the surface water input in Scenario 2.

Changes in EV are -4.49 million yuan under plan 1 and -2.88 million yuan under plan 2. Losses of EV per yuan of surface water savings are 1.59 yuan under plan 1 and 1.50 yuan under plan 2. Therefore, it is preferable for social welfare to set the groundwater price for agriculture to be lower than that for other industries, because plan 2 can reduce the groundwater input effectively.

Figure 13 shows the change in production by industry. Overall, the influence of plan 1 is larger than that of plan 2. Moreover, agricultural production is greatly affected by the water price reforms because the quantity of water input in agriculture is far larger than that in other industries. Therefore, agricultural production decreases under both plans.

Figure 14 shows the change in household demand for each good. This figure highlights that household demand decreases overall because of declining household income and that demand under plan 1 decreases more than that under plan 2.

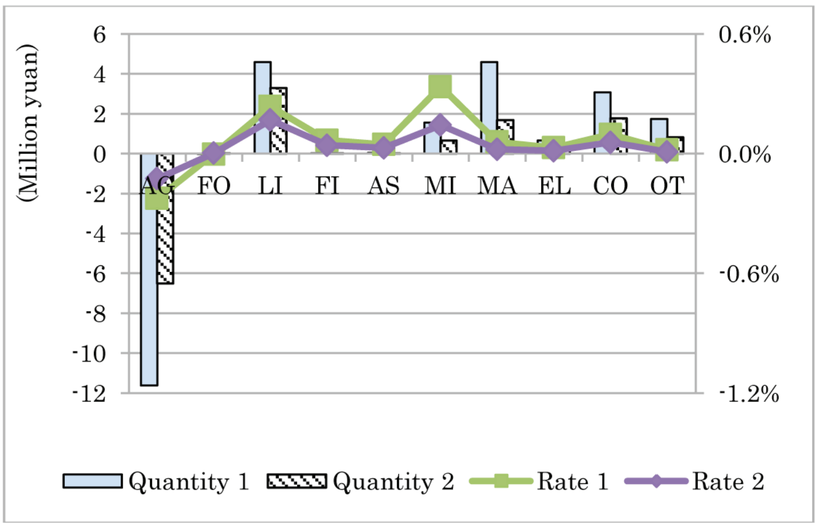

Figure 13: Change in the value of production in Scenario 2.

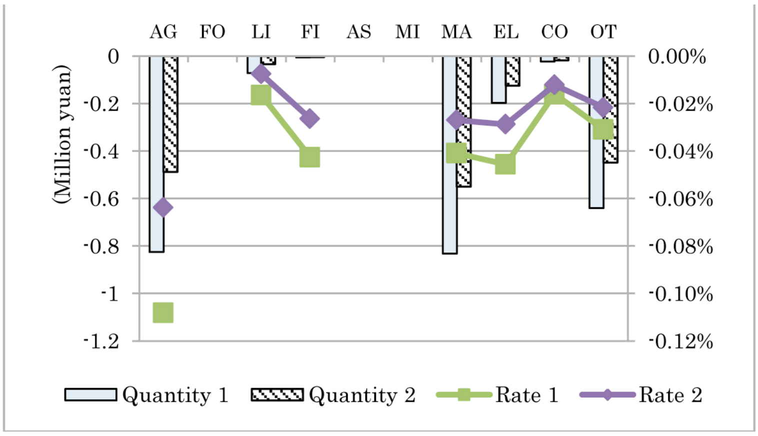

Figure 14: Change in household demand in Scenario 2.

Figures 15 and 16 show the changes in exports and imports. We can see that the influence of plan 1 is larger than that of plan 2. The decline in agricultural production in Zhangye affects agricultural production in other regions of China because Zhangye is recognized as a specialist seed producer.

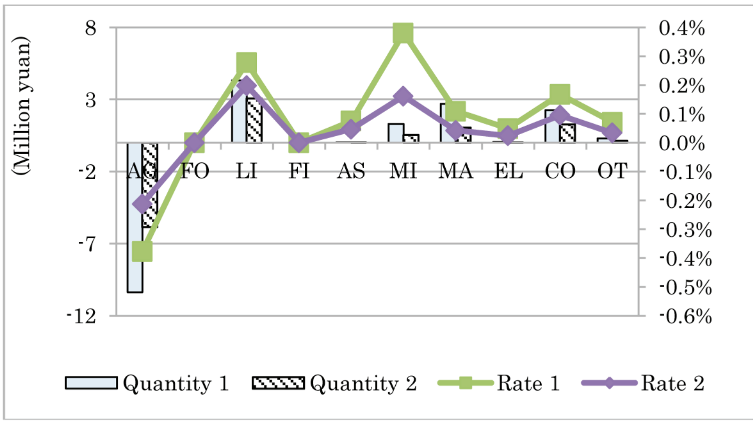

Figure 15: Change in exports in Scenario 2.

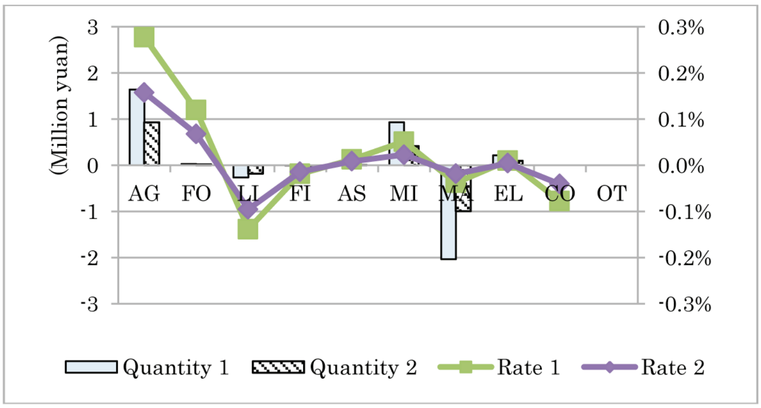

Figure 16: Change in imports in Scenario 2.

In summary, it is preferable, not only for primary industries but also for the whole society, to set the groundwater price in the agriculture sector to be relatively low and that in other sectors to be relatively high.

Conclusions

In this research, we analyzed how water pricing policies in Zhangye affect water demand as well as the local economy by modeling two water price plan scenarios. In the first scenario, we assessed the impact of doubling the surface water price and found that the amount of surface water decreases by 7% of the total surface water input, while the amount of groundwater increases by 84% of the total groundwater input. This is clearly an inefficient scenario, because the loss of EV per yuan of surface water savings is 14.58 yuan. In scenario 2, we analyzed the impact of two groundwater pricing plans and found that in order to control the groundwater input, the groundwater price should be relatively low in primary industries and higher in other industries.

One limitation of our model is that a conventional Cobb–Douglas-type function was used to manage water resources. It would be more realistic to employ a CES-type function for this type of modeling. However, when such a CES-type function is used, it is necessary to estimate the constant elasticity of substitution of the function for water resources management. It is thus preferable to estimate the elasticity value using, for example, a questionnaire, because the availability of statistical data on groundwater and surface water prices is limited.

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Farm level rainwater harvesting for dryland agriculture in India: Performance assessment and institutional and policy needs

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Abstract

The present study was conducted to assess the performance of farm ponds in 5 major rainfed states of India - Andhra Pradesh, Maharashtra, Karnakata, Tamilnadu and Rajasthan, during 2009 and 2010. The data points included sites in the field, farmers, implementing agencies, NGOs, scientists and policy-makers. Rainwater harvested was either used for supplemental irrigation or recharging the open wells. Rainwater harvesting structures of different types and size (10x10x2.5 m, 30x30x3m, 45x45x3m; 82x26x3m) were constructed on individual farms, especially for smallholders. The farmer's contribution to the cost of construction ranged from 10 to 80%. In many cases, farm level rainwater harvesting structures were highly useful for rainfed farming under climate change scenario and had a multiplier effect on farm income. In other situations, it was viewed as wastage of productive land. The farm ponds in Maharashtra resulted in significant increase in farm productivity (12 to 32 %), income and cropping intensity. The ponds were also used for aquaculture for 6-7 months, providing additional net income up to US$ 200 / pond/ annum. Similarly, in Andhra Pradesh farm pond water was useful for supplemental irrigation to mango tree plantation, vegetables and other crops and animals and resulted in significant increase in household income adding net returns of US$ 120 to 320 ha^{-1} $annum^{-1}$. In spite of its great relevance, the acceptance and adoption of farm pond was not very high except in Maharashtra. The study analysed the factors responsible for success and failure. Though the customization of package and technology were important factors, the institutional mechanism, governance at grass root level and people's participation played greater role in the success. Based on the lessons learnt, different policy and institutional options are proposed for promoting farm-level rainwater-harvesting for dryland agriculture.

Introduction

Rainwater management is the most critical component of rainfed farming, which accounts for about 56 % of the total net sown area in India. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in situ* or the surplus runoff is harvested, stored and recycled for supplemental irrigation. Hence the rainwater harvesting for the past couple of decades has been an important component of rural and agriculture development programmes in India. The importance of rainwater harvesting for agriculture has further been increased as an adaptation strategy in view of increased climatic variability and frequency of extreme weather events.

Research institutions and agricultural universities have worked on designing of efficient rainwater harvesting structures for different rainfall regions and soil types, effective storage of harvested water and method of its efficient use in the Indian context. Since community based initiatives have their own limitations, currently the rainwater harvesting is being promoted at individual farm level. Thousands of farm ponds (dugout pond) have been dug in different rainfed regions of India during the past one decade under different government schemes and to some extent by voluntary agencies. However, the impact of these efforts on agriculture as indicated by the core studies (Rao *et al.* 2009) and press and media has not been very satisfactory especially in terms of enhancing agricultural productivity and farm income. Moreover, no comprehensive study has assessed the performance of rainwater harvesting at farm level in terms of its potential utility and related institutional and policy needs in different agro-climatic regions. Therefore the present study was conducted to assess the performance of farm ponds/rainwater harvesting structures (RWHSs) in five major rainfed states of India representing different agro-climatic regions.

Sampling design and data

Five major rainfed states of India namely; Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu and Rajasthan were selected for the study at first stage. At the next stage sample districts were selected purposively representing diversity from the selected states as presented in Table 1. Thus, the study covered a sample size of 100 farmers with rainwater harvesting structures spread over 5 states under different rainfall and soil situations during the year 2009-2011. Besides farmers, the data points included sites in the field, programme implementing agencies, research scientists, relevant non-governmental organizations (NGOs), policy makers and on-farm trails of All India Coordinated Research Project on Dryland Agriculture (AICRPDA) in different regions.

Table 1: Distribution of sample households across states and districts

State	Districts	No. of block	Rainfall (mm)	Sample farmers	Soil type	Major production system
Andhra Pradesh	Chittoor	2	700	10	Loam	Paddy, sorghum, mango
	Ananthpur	2	500	10	Alfisol	Groundnut, castor, sorghum
Maharashtra	Akola	2	834	20	Vertisol	Cotton, pigeon pea, chickpea
Karnataka	Bangalore rural	2	900	20	Alfisol	Finger millet pigeon pea
Tamilnadu	Vellore	2	795	20	Alfisol	Sorghum, coconut
Rajasthan	Bhilwara	2	650	10	Inceptisol	Maize, groundnut
	Jodhpur	2	350	10	Aridisol	Pearl millet, pulses

Results and discussion

The rainwater harvesting at farm level under scientist managed on-farm trials conducted through All India Coordinated Project on Dryland Agriculture (AICRPDA) centers in their Operational Research Project was found to have good potential under different production systems and soil and rainfall situations (Table 2). The initial investment on construction of farm ponds up to 70 per cent was supported from the project. The additional net returns due to farm pond in different agro-climatic situations ranged from US $ 26-47 to US $ 186-466 per hectare. This assessment clearly substantiates the line of thinking that encourages increased public investment on farm level rainwater harvesting. However, the performance of farm level rainwater harvesting adopted by farmers under different government programmes and areas, has not been same and had shown mixed results.

Table 2: Performance of on-farm trials of farm ponds under different agroclimatic regions

Rain fall (mm)	Major soil types/ order	State	Major production. systems	Type of farm pond	Potential benefits		
					Increment in system's yield (%)	Additional net returns (US $ ha^{-1} $annum^{-1}$)	Unit cost of structure (US $)
500 to 750	Alfisols	Andhra Pradesh	Sorghum, castor based	250 m^3 farm pond with lining + sprinkler with 3 hp pump set	15-25 (Increase in cropped area 10-15%)	84-131 per farm pond/ annum	1024
			Groundnut, castor based	Water harvesting and recycling through farm ponds with lining with soil + cement (6:1 ratio)	*20- 24 (*+diversification into vegetables)	72-121	1024
	Inceptisols	Rajasthan	Maize based	500 m^3 farm pond with lining + sprinkler with 3 hp pump set	20- 25 (+diversification + bring waste-land into cultivation*)*	158-224	1397
	Vertisols	Gujarat	Groundnut based	Recharging defunct open wells through filters (Retains 67% sediment load and enhance ground water level) *(*filter and deepening of the defunct well)	15-30	26-47	931
750 to 1000	Alfisol	Karnataka	Finger millet based	250 m^3 Farm pond with lining + sprinkler with 3 hp pump set	15-20 (+10-15% more area under vegetables)	102-224	1024
	Vertisol	Madhya Pradesh	Soybean based	1000 to 4000 m^3 pond without lining mainly for large farmers	20-40 (+diversification into flori-horticulture	149-298 per pond of 1000 m^3	1.6 per m^3
		Maharashtra	Cotton based	500 m^3 farm pond without lining + sprinkler with 3 hp pump set	20-25 (+ 15-20 % increase in cropped area)	149-298 per pond	1397
> 1000	Inceptisols	Jammu & Kashmir	Maize based	250 m^3 farm pond with lining + sprinkler with 3 hp pump set	25 (+ diversification)	84-186 per pond	931
	Oxisols	Jharkhand	Paddy based	1000 m^3 to 4000 m^3 farm pond with lining + sprinkler with 3 hp pump set	30-50	279-381	1862-6518
	Vertisols	Madhya Pradesh	Paddy, soybean based	250 to 500 m^3 farm pond without lining + sprinkler with 3 hp pump set	20-25 (+higher diversification)	130-335	838-1304

Note: 1 US$ = INR 53.70

Farm level rainwater harvesting in different states

The rainwater harvesting systems (RWHSs) practiced in different states of India through different types and size of individual ponds dugout under different public funded schemes such as Mahatama Gandhi National Rural Employment Guarantee Scheme (MNREGS), Integrated Watershed Management Programme (IWMP), National Agricultural Development Programme (RKVY) and National Horticultural Mission (NHM) were assessed. The farm level rainwater harvesting though was a need-based intervention taken up as part of these programmes but the demand in majority of the cases did not come from the farmers indicating their low level of awareness and participation. The rainwater harvested and stored through farm ponds on individual farmer's field was recycled mainly for supplemental irrigation during dry spells. In some villages in Tamilnadu and Andhra Pradesh these structures were dug in the vicinity of open wells and were used as percolation ponds for their recharging. In Jodhpur, Rajasthan, rainwater was harvested in an underground cistern locally known as *Tanka* which is an age old practice. The harvested water was used for drinking purpose as well as to provide water to few perennial plants near the water source. *Khadin,* which is an ancient method of rainwater harvesting, was practiced in Rajasthan mainly in hyper arid areas with annual rainfall <300 mm, wherein rocky catchments are used to collect runoff which is allowed to percolate in the soil to raise crops in winter (rabi) on the conserved moisture.

The size and initial investment on RWHSs varied significantly in different states (Table 3). The harvested water was not utilized by using micro-irrigation systems in most of the states indicating scope for increasing efficiency of water use. The structures of different types - farm pond, percolation pond and *Tanka* of different size (10x10x2.5 m, 30x30x3m, 45x45x3m; 82x26x3m etc.) - were constructed on individual farms under various government programmes with preference to small holders. The farmer's contribution ranged from 10 to 50%. All were open structures except customised concrete covered structures called '*tanka'* and *'Jal kund'* in western Rajasthan where evaporation losses are very high due to higher temperature and wind velocity. The farm ponds in the black soil area were not lined however the lining with LDPE sheet or other cost effective alternative was required in the red/sandy soil area to minimise seepage loss.

It was critically important to decide the appropriate size and location of the RWHSs depending on the runoff potential and slope of the catchment area and called for the involvement of technically qualified person. Since only some farmers (not more than 30% in a village) opted for the RWHSs, practically the catchment area for the ponds of any farmer was more than his own field. In many cases, except Akola in Maharashtra, Vellore in Tamilnadu and Chittoor in Andhra Pradesh, the location of RWHSs was not technically appropriate and decided either on the basis of convenience of farmer or the contractor who dug these structures. In Akola district, several farm ponds were dug appropriately across the drainage line. In Chittoor the number of fillings were more also because of lateral seepage.

Implementation strategy

The strategy of implementation of the programmes was not same in all the states and to a great extent influenced the usefulness of these structures. In 'better performing districts' such as Chittoor, Akola and Vellore, in the beginning the farmers were sensitized on the importance

Table 3: Details of rainwater harvesting structures in different states, India

District (State)	Average land holding (ha)	Size of farm pond	Purpose	Average initial investment (US $)	Farmer's contribution (% of total)	No. of fillings per year	Access to water lifting device (% farmers)	Extent of recharging open wells (feet)	Method of irrigation	Inlet/ outlet pitching (% pond)	Relevant schemes
Chittoor (Andhra Pradesh	3.31 (2.01-4.0)	100 m^3-700 m^3	Supplemental irrigation, diversification	521	25	6	80	-	In furrow with PVC pipe- 74%; MIS- 26%	75	IWMP
Anantpur (Andhra Pradesh)	3.6 (1.9-5.6)	150 m^3-600 m^3	Recharging, Supplemental irrigation by few farmers	577	10	2	15	10-15	-	10	MNREGS
Bangalore R (Karnataka)	1.6 (1.04-3.5)	100 m^3-500 m^3	Vegetables and perennials on the fringes	410	10	-	5	-	-	10	IWMP, MNREGS
Akola (Maharashtra)	6.0 (2-16)	900 m^3- 2500 m^3	Supplemental irrigation, diversification	1527	10	4	100	-	Sprinkler- 100%	85	RKVY, NHM
Vellore (Tamilnadu)	3.05 (2.2-6.4)	500 m^3- 1800 m^3	Recharging open wells	801	15	3	75	12-18	In furrow with PVC pipe- 65% MIS- 35%	65	IWMP, MNREGS
Bhilwara (Rajasthan)	6.55 (3.5-9.7)	500 m^3- 2200 m^3	Supplemental irrigation	1415	10	1	50	-	In furrow with PVC pipe- 62% Manually- 38%	60	NHM
Jodhpur (Rajasthan)	3.85 (2.1-11.5)	Underground tank (Tanka): 30000 l	Drinking, Supplemental irrigation in fruit plants	1100	50	3	20	-	In furrow with PVC pipe- 43% Manually- 67%	90	IWMP, NHM

Note: 1 US$ = INR 53.70

and potential of rainwater harvesting for enhancing agricultural productivity. Dhan foundation - an NGO in Chittoor – and Agricultural officers in Akola and Vellore played proactive role in creating convergence and helped farmers accessing water lifting pumps, micro-irrigation system (MIS) - sprinkler and drip - and improved seeds. Once the farmers got convinced on the need of RWH structures, the size and location of farm pond was decided together by farmer and the project staff depending on the runoff potential and farmer's need. A series of farm ponds were constructed across the drainage line along with suitable silt trap and inlet and outlet pitching with stone. The harvested rainwater was utilized by using sprinkler/ drip system for supplemental irrigation in crops and perennials by majority of farmers. Within a span of 3 years, 200 farm ponds were constructed in selected village in Akola. Farmers' contribution in cash, kind or labour was mandatory. Organizing farmers into self help groups (SHGs) enabled them to share the water lifting devices and improved technology and grow high value crops. A sustainability fund was created through farmers' contribution. Farmers successfully worked as community and took major responsibility of maintenance and repair of common structures.

On the other hand in 'poor performing districts'- Bangalore rural, Anantpur, Bhilwara and Jodhpur - the farmers' participation was poor and the size of pond was mostly pre-decided and its location was decided in majority of the cases by the contractor on behalf of the department. Majority of the farmers were not able to utilize the harvested rainwater in the absence of water lifting device as reported earlier by Kareemulla *et al.* (2009). The rainwater harvesting was not promoted as complete customized package. Moreover there was no convergence to improve access to water lifting device and MIS. About 20 per cent ponds were dug in such a way that the excavated soil was spread covering area more than the area of actual pond and making that area uncultivable.

Impact on productivity, income and livelihood

Rainwater harvesting and its utilization through farm pond/percolation ponds had a significant impact on farm productivity and household's income, however their performance was mixed one (Table 4). In many cases they were highly useful for rainfed farming and had a multiplier effect on farm income. At the same time these structures were a total failure in other situations and were viewed as wastage of productive land.

The crop and livestock productivity and farm income increased significantly in Akola and Chittoor districts due to farm ponds. Increment in productivity of different rainfed crops in these districts ranged from 8 to 45 per cent. Moreover, the gross cropped area also increased by 20 to 26 per cent. As a result of availability of supplemental irrigation using harvested rainwater, the farmers planted additional fruit plants and it also enhanced the productivity of existing fruit plants namely mango in Chittoor and coconut in Vellore. With the provision of supplemental irrigation, not only the productivity of mango increased but their fruiting was also regularized. For some of the farmers the life got changed due to farm pond in Chittoor. They started earning additional income from higher production of mango and vegetable crops (US$ 120 to 320 ha^{-1} $annum^{-1}$) lifting debt-ridden farm families out of poverty. From the savings they purchased a few sheep and cow and put their children in school. Some acquired diesel operated pumping-set for own use and for renting to others for lifting water from farm-pond. Thus the farm pond had a multiplier effect on farmers' income with additional net returns ranging from US $ 500 to US $ 860 per annum per household.

Table 4: Impact of farm level rainwater harvesting on farm productivity and annual income

District	Increase in gross cropped area (%)	Increase in productivity of different rainfed crops* (%)	Additional fruit plants raised per household (No.)	Increase in existing fruit plant productivity (%)	Increase in fodder availability (ton)	Increase in livestock productivity**	Additional employment generated (Mandays/ annum)	Additional income per household (US$)
Chittoor	19.5	8-35	46	31	2.7	14	232	700
Anantpur	9	5-11	-	-	1.9	-	66	317
Akola	25.8	12-45	7	24	3.5	9	196	927
Bangalore rural	-	0-8	6	-	0.5	4	26	47
Vellore	5	5-13	16	51	1.5	7	93	503
Bhilwara	8.5	4-11	22	19	2.0	7	72	307
Jodhpur	-	-	12	15	1.2	5	38	177

*Increase was due to supplemental irrigation and also due to improved varieties and package of practices

**Increase was due to improved access to fodder and water

Similarly in Tamilnadu, supplemental irrigation to coconut from the recharged wells added net farm income of US $ 370 to US $ 640 per annum. Growing of vegetables on the fringes of farm pond by number of farmers resulted in improved access to green vegetables for home consumption.

In Akola district the crop and variety mix was also changed significantly. There was an increase in *kharif* (rainy season) and *Rabi* (winter season) cropped area and multipurpose plants on the fringes of the pond. The farmers could grow good chickpea crop in winters in large black soil area by providing only one sprinkler irrigation using pond water; the crop otherwise had very low productivity. The farmers shifted from local cotton variety to Bt Cotton with a provision of supplemental irrigation. Some farmers also used ponds for aquaculture for 5-6 months and earned additional net income up to US $ 200 pond^{-1} annum^{-1}. The positive impact of farm ponds on agricultural productivity as well as farm income was observed to be highest in case of Akola district followed by Chittoor and Vellore districts and it was least Rajasthan and Karnataka.

The farmers in Chittoor also got organized into self help groups (SHGs) and created sustainability fund through their contributions. Adoption of improved agricultural technologies also increased significantly after the farmers got organized and had increased access to water. In Anantpur, it was not as beneficial, small farm ponds without lining had low acceptance by the farmers because of their poor utility due to high evaporation and seepage loss. Irrespective of the farmers' need, all the ponds excavated under MNREGS were of standard same size. Only 36 percent of the ponds were appropriately located and useful. In Tamilnadu the percolation ponds resulted in recharging of open wells that enhanced farmers' access to irrigation and farm income significantly. The performance of majority of farm ponds in Karnataka was far below its potential mainly because of poor participation and technical soundness of RWHSs, farmers considered the maintenance of farm pond as wastage of his labour and were searching for other employment options. About 47 percent did not get runoff due to wrong location. Inappropriate design, size and location of number of farm ponds in Rural Bangalore, Anantpur and Bhilwara districts resulted in poor rainwater harvesting.

In Bhilwara, the net benefits due to a farm pond ranged from US $ 132 to US $ 345 per annum. Potential benefits could not be harnessed also due to inefficient utilization of harvested water for want of proper water lifting device and MIS and low adoption of improved package of practices for crop and livestock production.

In Jodhpur, where soils are sandy and evaporation losses are high, the rainwater harvested in a covered concrete underground structure (*Tanka)* was mainly used for drinking purpose, animals and supplemental irrigation to fruit plants in the initial stages. The adoption of small *Tanka* by farmers was low mainly because the net benefits from perennial component raised with the help of harvested rainwater in *Tanka* were small but demanded farmer's engagement throughout the year for its maintenance and protection. The high capital requirement was hindrance in adoption of large size '*Tanka*' needed to support an economically viable size of orchard.

A case study of *khadin* system of rainwater harvesting was conducted in Jodhpur district which involved 6 farm households having 12.5 ha land. Besides farmers land, catchment also included nearby rocky wasteland of about 15 ha. Three small check-dams and peripheral bund as part of *khadin* had initial investment of US $ 9500 at current price of year 2012 which had public funding and has life of more than 20 years. As a result the gross cropped area increased by about 90% besides addition of 250 plants of arid fruits – *Zyziphus moritiana* and *Cordia mixa*. Consequently these 6 farmers are earning additional net return US $ 1900 from crops and US $ 850 from fruit plants every year.

Provision of proper inlet and outlet of the pond with stone pitching was needed to ensure longer life and better use of the pond. There was also a need for higher involvement of female members, who actually managed the rainfed agriculture for large number of households, and played role in rainwater harvesting and utilization efforts. The returns observed to be higher in area with black soils and annual rainfall >500 mm as compared to red/sandy soils and annual rainfall <500 mm. Lining of the pond was needed in the red/sandy soils, however was not required in the black soils. Besides tangible benefits the farm ponds provided many intangible benefits like minimizing run off losses, soil losses, nutrient losses, preserving eco- systems and providing drinking water for animals and humans.

Determinants of performance of RWHS

It is clear from the above analysis that the integration of farm pond in the dryland farming systems has a great potential to increase farm productivity and income in these regions. However, its adoption and net benefits varied significantly among different districts/states mainly due to difference in the implementation approach, level of participation, technical soundness, farmer's resources and knowledge and amount and intensity of rainfall. To analyze further the selected districts were grouped into 'Better performing districts' – Chittoor, Akola and Vellore and 'Poor performing districts' – Anantpur, Bangalore rural, Bhilwara and Jodhpur. The critical factors influencing the performance of farm ponds were identified through stakeholders' workshop and PRA. Most of these factors as presented in Table 5 were institutional in nature. For each of the factors an index value was calculated on the scale of 1 to 10 based on the score given to the indicators for each factor. For example the value of index in case of 'farmers participation' was calculated based on the indicators such as farmers contribution in cash or kind, farmer's role in deciding the size, location and design of the farm pond/RWHS, involvement in repair and maintenance of pond, extent of utilization of harvested rainwater, and frequency of interaction among farmers/SHGs and implementing agency for managing farm ponds. Each indicator was allocated 2 marks. The analysis shows that the index value was significantly higher in case of 'better performing districts' especially for 'farmers participation', 'farm pond as part of customize package', regular technical backstopping in initial phase', technical soundness of the structures and its economic viability indicating high importance of these factors in determining the performance of farm ponds.

Non-utilization of harvested water due to non-availability of water lifting devices/micro-irrigation system or lack of appropriate crops/plants discouraged its adoption. The adoption of farm pond by small farmers with less than 2.0 ha land in dryland areas was observed to be very low mainly due to the fact that the small farmer also uses his labour for earning wages to stabilize his household's income and also because the potential of rainwater harvesting and consequent increase in farm returns is low due to small size of the holding. It was also observed that rainwater harvesting in arid regions with <400 mm annual rainfall was more useful for sustaining appropriate number

Table 5: Factors influencing the performance of RWHS (rating index scale: 1 to 10)

Critical factors	Index value		Drivers/Conditions
	Better performing districts	Poor performing districts	
1. Farmers participation	7.5	3.5	• Sufficient efforts for sensitization • Participation of farmers in deciding the size and location of RWHS • Handholding services and liaison work by extension agency in the initial phase • Higher probability of additional net returns
2. Provision of farm pond as part of a complete package (pond, water lifting device, MIS, improved varieties and package of practices, etc.)	7.0	2.0	• Increased usefulness of farm pond and efficiency of resource use and adoption • Multipliers effect on farm productivity and income
3. Convergence of relevant government departments	3.5	2.0	• Bringing them together reduces transaction cost and creates synergy
4. Access to information on technology, market and government support at village level	6.5	3.5	• A person/center is required at village level for knowledge support
5. Regular technical backstopping in initial phase	7.0	3.5	• Building capacity of farmers to use technology independently
6. Easy and cost effective access to technical inputs like water lifting pump, improved seeds, sprinklers, etc.	6.0	2.0	• Reduction in the transactions cost • Higher ease of adoption
7. Technical soundness of RWHS in terms of location, size, design and construction	7.0	3.0	• Catchment: Pond ratio • Drainage lines and location of pond • Inlet and outlet pitching and silt trap • Cost effectiveness
8. Economic viability of farm pond	6.5	2.5	• The net returns should be greater than the opportunity cost of labour and capital
9. Rainfed agriculture as major source of livelihood for farm household	6.5	4.5	• Farm households that did not have alternate source of livelihood took more interest in adoption of farm pond.

of fruit and multipurpose trees to stabilize farm income provided there was provision of fencing, and also water for drinking and animals and for growing *rabi* crops on conserved moisture.

Technology, policy and institutional needs

The analysis has shown that in rainfed semi-arid and arid regions, the farm level rainwater harvesting/pond have tremendous potential to increase the farm productivity and income.

However, construction of farm pond/RWHS is both capital and labour intensive, which poor farmers in drylands may not be able to afford and hence need to be supported through capital subsidy. Though there are provisions for creating farm ponds/RWHS under different public programmes like watershed development, MNREGS, NHM, RKVY, etc; but their poor adoption and realization of low benefits to the farmers were found to be mainly due to lack of proper institutional and policy support. The participation of farmers in true sense was the single most important factor influencing the adoption and potential benefits from RWHSs. The participation of farmers cannot be ensured unless they are sufficiently sensitized and assured of considerable additional net returns by having a farm pond/RWHS. Lack of capital and location specific solutions, high transaction cost, no convergence among multiple actors working for water harvesting, poor access to cost effective water lifting devices, low net returns from dryland agriculture, etc. were the major constraining factors. Though the customization of package and technology were important factors, the institutional mechanism, governance at grass root level and people's participation played much greater role in the success of farm level rainwater harvesting.

The farmers in the drylands especially the small holders do not depend only on crop production, which has high risk and hence allocate their resources and time for other livelihood activities such as livestock, and agricultural and non-farm wages in their village or outside. In such situation the farmer is ready to adopt the farm ponds/RWHS only if it presents a possibility of considerable increase in net returns which are higher than its opportunity cost. Therefore, the following technology, policy and institutional arrangements (Table 6) are needed to promote farm level rainwater harvesting for dryland agriculture:

Table 6: Conditions to be met for adoption of farm level rainwater harvesting

Policy and institutional needs	*Technology needs*
• Major proportion of the initial investment on RWHS has to come from the government by converging different schemes like MNREGS, RKVY, watershed programme etc. • Need to identify points and strategy for such convergence and this should be initiated by the Ministries at national as well as state level from the top. • Operationalization of farm pond/RWHS need to be done as a customized package for rainwater harvesting and utilization (including inlet and outlet pitching and lining of pond, water lifting pump, micro-irrigation system, improved package of practices and varieties etc. • Flexibility in relevant government schemes to decide the size of farm pond as per need • Need to launch awareness campaign through radio, newspaper, electronic media, etc. on the need and benefits of farm level rainwater harvesting • Provision of technical backstopping at village level especially in initial phase: Extension worker/creating service provider farmers (handholding services, equipment, liaison work, follow up until the experimental stage is finished) • Creating water harvesting self-help groups (SHGs) would provide better access to technology and increased opportunity for efficient water harvesting and utilization due to mutual learning and cooperation.	• Low cost and easy to handle water lifting devices and micro-irrigation system matching the needs of different category of farmers needs to be developed. • Location of the RWHS needs to be identified by the technical person by involving the farmers/ community. • Farmers must be properly trained to handle and maintain micro-irrigation systems and make best use of harvested water. • Need to generate maps on water harvesting potential in different regions based on the data on amount and distribution of rainfall, soil, vegetation, temperature etc.

Conclusions

It was seen that the adoption of farm ponds was higher if they were appropriately sized, designed and located to get more water with provisions to use water efficiently. The harvested water should be used not only by efficient methods like drip or sprinkler but should also be used for the crops which optimize the farm returns. The farmers should be suggested with different options for using harvested water along with their package of practices and market opportunities. Hence, there is need to implement RWH as a customized package for harvesting and efficient utilization ensuring effective facilitation in the initial phase by putting technically qualified and trained person at village level. The farm level rainwater harvesting has a great potential to improve productivity and farm income in dryland areas of India and other similar regions provided suggested technology, policy and institutional needs are met.

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Assessment of the agricultural productivity of a traditional agricultural system in Tunisia

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Abstract

The study focused on *Jessour*, a traditional farming system in south Tunisia, which uses water collected from far away in mountainous areas after precipitation there. The study analyzed and estimated the actual agricultural productivity, the productive potential, and the prospects for utilization of the system. Data on crop yields, operation and maintenance cost and farm system expansion and upgrading were collected by a questionnaire to the farmers through a survey. The result shows that Jessour system can permit olive and olive oil production, cereal crops, vegetables, and fruits for domestic consumption throughout the year. However, the crop yields from Jessour are extremely unstable under unsettled meteorological conditions, which have become frequent in recent years. The result also showed that more and more farmers are cultivating fodder crops in upstream catchment area to make up for reduced crop yields in recent years. However, cultivation of catchment area is difficult because of the unfavorable conditions to collect water. Therefore, farmers are cultivating drought resistant plants such as barley and legumes. Cultivation of upstream catchment area may however impact negatively on downstream farmland cultivation.

Introduction

Effective water utilization and water management will become more important in areas facing water shortage. Thus, it is very important to find solutions to overcome water shortage and save water resources. This study focused on an agricultural technique based on a traditional water collection and use on a seasonal stream after rainfall events.

There are various ways of farming using runoff that are practiced in arid regions in North Africa, and 'Jessour' system in Tunisia is one of them. This system can be found in the arid and mountainous zone (El Amami 1984; Mechlia and Ouessar 2004). In seasonal riverbeds, small dams made with earth and stones are constructed. The basic structure of Jessour consists of three main parts. One of them is catchment area which receives precipitation, runoff water, and sediments to the cultivation area. The second part is dyke and spillways which are installed on center of wadi, and the last part is cultivation area to be used as farm field after the gentle slope was formed by sediments. Soil accumulates in front of these dams so that terraces with a soil depth of 1 to 2 m are formed (ILEIA 1986). On the terraces, flood water is impounded and infiltrates into the soil. The infiltrated water makes agricultural activities possible in these arid regions. On the terraces, various kinds of fruit trees such as olives, almonds, dates, and figs, and grain and legume crops are cultivated (Bonvallot 1986). Dams and spillways must be built firmly and their maintenance must be very consistent to make this agricultural system last as long as possible (ILEIA 1986). Mechanism of water collection and holding of Jessour system was studied by Schiettecatte *et al.* (2005). The purpose of this study is to analyze and estimate the actual agricultural productivity, the productive potential and the prospects for utilization of the system.

Material and methods

Methodology

The study analyzed the crop yields, economic balance for the past decade and future plans by using data obtained from questionnaires about Jessour. The study analyzed and estimated the actual agricultural productivity, the productive potential and the prospects for utilization of the system.

Site description

Tunisia is the smallest country in North Africa, measuring 1200 km from north to south and an average of 280 km from east to west. The main geographical zones are Djerba and the Djeffara-Ouara in the northeast, the Matmatas and the Dahar in the centre, and the Oriental Erg in the southwest (Ouessar *et al.* 2002). The climate is arid Mediterranean to desert. The annual rainfall ranges between 150 and 230 mm (Ouessar *et a.l* 2003). Rainy season occurs during the cold season from October to March, and dry season from April to September. Farm fields of the study site were located in three villages around Beni-Khadache-city (Bhayra, Zammour, and Lathmane) and one village (Boughrara) around the Institut des Régions Arid (IRA).

Meteorological data

Meteorological data were collected at Zammour site which is located at the center of the three study sites (Lathmane, Zammour, and Bhayra). The altitude of weather station is approximately 580 m. The observation was started on 10 December 2010 and involved monitoring of weather information.

Soil physical properties

The study collected soil samples from the catchment area and cropping area at each depth where we installed soil water content sensors (surface, middle layer and deepest side layer) in order to measure soil texture, hydraulic conductivity and soil water retention curve. Two different soil moisture sensors, EC-5 and ECHO2-TE, were installed in each study site at ‘‘surface’’ (15 to 20 cm from soil surface), ‘‘middle layer’’(30, 55, 65 and 100 cm), and ‘‘deep side layer’’(60, 110, 130 and 200 cm depending on the depth of the soil. The deepest side layer is maximum depth which can be dug by hand work. Rooting depth of crops in the fields is 0.6 to 1.7 m (USDA 1983; FAO 1998). Especially, rooting depth of olive which is main crop on the fields is comparatively shallow at 1.2 to 1.7 m. Therefore, it can be deduced that root of the crops do not use soil water which is under deep side layer.

Geographical survey

We calculated dimensions, slope, and points of each construction in the study sites by using simplified highly accurate GPS. The survey covered the following:1) Bleeding channel in catchment area, 2) Dike and spillways, 3) Cropping area, 4) Catchment area

Land use

The number and kind of the fruit trees on each cropping area were identified by land use survey. In that survey, the study also identified the place and dimensions of cropping area of cereals and pulses.

Rainfall simulation

The study conducted the rainfall-runoff simulation by using Kamphorst infiltrometer in order to estimate amount of discharge from catchment area in Lathmane site. Experiment position was selected in the upstream of the catchment area; average slope was 23 %.

Socio-economic survey

A socio-economicy survey about Jessour was conducted by administering a questionnaire. The survey was only conducted at Lathmane site. The questionnaire consisted of the number or kind of cultivated trees, crop yields in the past decade of olive and other crops, and economic balance.

Results and discussion

Soil characteristics

Soil texture of cropping area was almost sandy. The soil texture of the catchment area and sediment in reservoirs (Marjel and Fasquia) was sandy clay. The soil of the catchment area which is a source of supply of the sediment on cropping area was classified as sandy clay soil. When the soil flows out to the cropping area by rainfall, fine texture soil flows to the downstream. The dyke blocks the flow and sediments accumulate in front of the dyke but fine texture soil such as clay floats in the water and does not settle out and flows over the spillway. Therefore, the soil texture in cropping area has high percentage of coarse-grained soil.

The study analyzed the water transfer characteristic of each soil depth in the study sites. Soil water retention curve and unsaturated hydraulic conductivity were determined. The results were typical of sandy soils. Volumetric water content, from which the suction reached to the depletion of moisture content for optimum growth, was distributed from 0.05 to 0.12 $m^3 m^{-3}$ in all cases of the soil samples. The study showed that if soil water content is not less than 0.13 as pF 3.0 at the end of the dry season or the end of September when the rain season starts, crops may be subjected to some water stress but crops can live without irrigation until the next rainy season.

The result of the chronological change of soil water content showed that the response of soil water content to precipitation at the surface and middle layer was quick. Soil water content sensors reacted 3 times to rainfall events throughout the year. The first event was on 28th January 2012 as16.2 mm/13 hr, next event was on 21th February 2012 as 36.2 mm/16 hr, and final event was on 9th March 2012 as 8.6 mm/51 hr. The chronological change of soil water content of deep side layer reacted to only the rainfall event in March. The soil water content rapidly decreased until 0.30 after reaching the saturation point. The main crops grown on Jessour such as olive and fig use soil water around this depth.

Geographical properties

The study analyzed the basin area, the structure of the site, the slope and land use at Lathmane site using GPS. The study surveyed the outer border of the basin, channels on catchment area, dykes, cropping area, catchment boundary and each border.

The study numbered the cropping area from the downstream side and calculated the area of catchment and cropping area in order to calculate the catchment to cropping ratio, CCR. The total cropping area was 25,231 m^2, total catchment area was 211,464 m^2. Average CCR of whole river including subsidiary rivers is 8 to 1. Average dimensions per parcel of land was 1,515 m^2 on main river, and 870 m^2 of whole cropping area including subsidiary river. It is difficult to find the place where we can construct a new Jessour in this watershed.

EL Amani (1984) indicated that average CCR of Jessour system which freckle in south of Tunisia is approximately 5. Gabriels *et al.* (2005) however showed that adequate CCR of Jessour system is 7.4. Average CCR in Lathmane site is 8. Thus, Jessour system in Lathmane site meets the requirement of the cropping area. Meinzinger (2001) showed that adequate CCR could be calculated as follows:

$$CCR = (WR - P)/(C*P \qquad (1)$$

where CCR is catchment area to cropping area ratio, WR is annual water requirement of crops, P is annual mean precipitation, and C is average effluent ratio.

Annual water consumed in Lathmane site was 313 mm while the mean annual precipitation was 166 mm/year from 2011 to 2012 in Zammour. Average effluence ratio was assumed as 6.7 %. With these values applied to equation 1, the CCR was:

$$\mathrm{CCR} = \frac{(313 - 166)}{0.067 * 166} = 13.2$$

It has to be noted that the calculated effluent ratio of 6.7% is very low. Gabriels *et al.* (2005) calculated the effluent ratio in south of Tunisia as 15.3%. If this value is used the CCR comes out to be 5.8:

$$\mathrm{CCR} = \frac{(313 - 166)}{0.153 * 166} = 5.8$$

Thus, the adequate CCR is 5.8, therefore an average of actual CCR as 8 is an adequate value.

The vertical cross section and cross section of the main river were made out for the calculation of amount of sediments, or longitudinal slope. The average slope of cropping area was 2.06%. The slope of the original ground was 5.15 %. The average sediment thickness on the cropping area was 2.0 m.

Land use

The planting density was 98 trees per ha and the planting interval was 12.6 m per tree. The average slope of the cropping area was 2.10 %. The average slope of the catchment area was 14.89 % on the right side and 10.48 % on the left side. The cultivated trees were olive trees and there were 57 trees, 53 fig trees, apple, peach, almond, pistachio and date palm. The planting interval of 12.6 m/tree is denser than 20 m/tree that is generally used for olive orchards in south of Tunisia. This result shows that the cropping area is keeping sufficient soil water for olive trees which are shallow-rooted trees and olive trees spread out their roots in the horizontal direction throughout the year.

On the other hand, several farmers till catchment area to cultivate fodder crops such as cereals or pulses. In addition, slope of catchment area normally is sharper than cropping area. In that case, effluent water directly flows out to downstream side, therefore, efficiency of water storage into the soil may be reduced.

Rainfall simulation

The result of the rainfall simulation at Lathmane site showed the relationship between effluent discharge and precipitation could be estimated using the formula:

$$Y=0.0008X^2-0.0391X-0.0833 \qquad (2)$$

where Y is effluent discharge (mm) and X is cumulative rainfall (mm). As a result, the amount of discharge was 2.6 mm, effluent ratio was 6.7 %. Gabriels et al. (2005) found 15.3 % as a result of the rainfall simulation at slope in the mountains in south of Tunisia. Possible causes for difference between these results may the changing of the soil surface condition by installation of the equipment, difference in the meteorological conditions and difference in the supposed rainfall intensity

Estimation of amount of inflow and water balance

The study estimated the amount of discharge into the cropping area by using formula of adequate CCR (1). The calculation period was from October 2011 to September 2012. The main rainfall event occurred 9 times and rainfall total was 191 mm

Equation of influent quantity (Ai) is as follows:

$$Ai=P*Er*Ca/Cr+P \qquad (3)$$

where Ai: Influent quantity (mm), P: Precipitation (mm), Er: Effluent ratio (0.067)

Ca: Dimensions of catchment area (m^2), Cr: Dimensions of cropping area (m^2).

The results showed that the amount of influent quantity was 343 mm with total rainfall of 191 mm. The calculation also used rainfall amount of 99 mm which was observed on 9 March 2012. The result showed that Jessour system can fill the role of disaster-prevention facility and found out the followings: 1) Overflow does not occur on the downstream by rainfall of 99 mm; 2) Water flow is from upper stream to downstream; 3) It takes one day to one week for floodwater to dry up; and 4) There is little possibility of water logging in all fields at the same time.

The condition for overflow to occur is limited to when a big rainfall event or high rainfall intensity occurs. However, precipitation of more than 200 mm/day was recently observed in South of Tunisia. The study calculated the outflow by using the effluence rate as 0.067, and found that when amount of precipitation reached to 200 mm, excess of inflow occured and spilled to the downstream.

Estimation of a water balance

The study considered the water balance at Lathmane site from the estimation of amount of the inflow and the result of the chronological change of soil water content. The result showed that the evapotranspiration of the field was 313 mm while the amount of inflow was 343 mm. Thus the water balance in the field was:

343 mm – 313 mm = 30 mm

The results show that the cropping area is keeping same quantity of soil water because precipitation in this year is average in quantity. In addition, orchard trees of main crop such as olive do not consume water from whole surface of the field. Therefore, the water balance may be more stationary than calculated result.

Economic analysis on Jessour system

The results of the questionnaire showed that crop yields per tree were higher than general average in southern Tunisia, indicating that Jessour system has high agricultural productivity. Crop yields per unit area of Jessour were approximately three times higher than in the rain-fed agriculture located in the flatland. The result from the questionnaires shows that even in the lean year, Jessour system could have a high agricultural productivity. Jessour system can allow the production of olive or olive oil, cereals, vegetables and fruits for domestic consumption throughout the year. However, farmers need income from other works for maintenance and operation of Jessour or agriculture.

Conclusions

The study on the agricultural productivity in the Jessour which is a traditional agricultural system in southern part of Tunisia highlighted the following:

9. Cropping area of Jessour has the capacity that can keep soil water content more than depletion of moisture content for optimum growth (pF 3.0) in the root zone throughout the year. Jessour can permit production of olive or olive oil, cereals, vegetables and fruits for domestic consumption. The soil surface conditions impact on the infiltration rate showed that it is possible to increase the amount of water storage into the soil by selecting and adjusting the timing of tillage in the field.

10. The result of comparison of crop yields between Jessour and rain-fed farming showed that the average crop yields are basically stable in Jessour system and current agricultural productivity is high. The environment impact is not high in comparison with irrigated agriculture using groundwater.

11. Even if the rainfall of larger than 200 mm/day occurs in the study site, Jessour system can save on runoff volume to downstream by collecting water at dyke and allows it to infiltrate at upper stream. This flood mitigation function of Jessour can alleviate the negative effect of climate changes in the future.

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Managing irrigation activities under water scarcity: The impact on farmers' revenue and the sustainable use of the water resources

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Abstract

¶Irrigation is a key to develop the agricultural production in the dry areas. This paper examines how farmers using the groundwater could cope with water scarcity. The study is based on farmers located in Sidi Bouzid, a semi-arid region in Tunisia. The objective is to monitor the farming system of the irrigated farms using groundwater and to assess the impact of the groundwater depletion on the cropping system, water consumption and farmers' revenue. The farm model was developed using the positive linear programming approach in order to simulate the impacts of strategic adaptation of farmers facing the water scarcity. T¶TThe results confirmed the importance of the groundwater depletion and the increase of the water salinity.¶ On average the land intensification rate had decreased by 27% for study period and the water consumption per hectare had also decreased by 11%.¶ The results of the simulations regarding the decrease of the water availability, the increase of the water price, and the increase of the land intensification showed that farmers have to adapt their cropping system accordingly. In each scenario their revenue may decrease substantially and their livelihoods may be threatened.

Introduction

Water needs for irrigation and food production constitute one of the greatest pressures on freshwater resources. In most of the irrigation schemes, the water demand is always greater than the supply allowed by the available structure (Faysse 2003). Agriculture accounts for around 70% of global freshwater withdrawals, reaching up to 90% in some fast-growing economies (UNESCO 2012). Thus groundwater is crucial for the livelihoods and food security for 1.2 to 1.5 billion rural households in the poorest regions of Africa and Asia, and for domestic supplies of a large part of the population elsewhere in the world.

The global groundwater abstraction rate has at least tripled over the past 50 years (UNESCO 2012). With the advent of the tubewell, and driven by the rapid growth of demand for agricultural and domestic uses, annual global groundwater extraction has increased in recent decades from 100 km^3 per year in 1950 to a current estimated use of about 800 km^3 per year (Wada *et al.* 2010). In addition to its capacity to answer growing water demand, groundwater also provides unique opportunities to cope with increased climate variability due to climate change (Wijnen et al. 2012).

In Tunisia, the groundwater is estimated at 2160 Mm^3/year which represents 45% of the annual available freshwater. Some 70% of the groundwater withdrawals are used for irrigation. The shallow aquifers provide 750 Mm^3 per year while the withdrawals reach 810 Mm^3 per year, used almost exclusively for irrigation. The excessive abstraction and the unwise use of the groundwater damage the water quality revealed in an excess in dissolved salts and a contamination with nitrates (El Ayni *et al.* 2012). The intensification of the smallholder agriculture, particularly in Sidi Bouzid region, led to an overuse of the groundwater exceeding 130%. Since 1985, some areas of this region were declared as prohibited areas for irrigation. The drawdown of the groundwater table reduces also the water flow rate. In order to satisfy his needs of water for irrigation, the farmer has to pump more and more or to drill deeper the wells. In both cases, the irrigation expenditures increases, reaching up to 40% of farming variable costs (Chemak *et al.* 2010). Also, in response to the decrease of the water availability, the farmer has to reduce his irrigated area which will affect his revenue. Within this context two questions need to be answered: (1) What is the impact of the groundwater depletion on the farming management?¶ (2) How the farmers could sustain their activities without compromising the water resources?¶

This study monitored the farming system of the irrigated farms using groundwater in Sidi Bouzid region and to assess the impact of the groundwater depletion on the cropping system, water consumption, and the revenue of farmers.

Water scarcity and the importance of the irrigation in Tunisia

Given the Mediterranean climate constraints, Tunisia has always been threatened by the water scarcity. The country receives an average rainfall of 250 mm per year with a highly variable distribution in time and space. In fact, the average annual rainfall is around 600 mm in the north, 290 mm in the centre and 150 mm in the south, it is ranging from 1500 mm in the extreme North to less than 100 mm in the extreme south. Sometimes, during short and intensive rainfall events, the rainfall may exceed the annual average values 2 to 12 times. In addition, unpredictable successions of dry years may seriously worsen the situation. This potential of water resources is mainly available in the northern region of the country, accounting for 84% of the total as compared to 12% in the central and 4% in southern part. Some 72% for surface water and about 28% of shallow groundwater and deep aquifers have less than 1.5 g/l of salt (Hemdane 2002).

The potential water resources are about 4860 Mm^3/year of which more than 90% were already mobilized. This quantity permits a water availability of only 480m^3/capita/, which is already under the water poverty threshold estimated at 1000 m^3/year (Lebdi 2009). It is expected that the availability might further decrease to 315m^3/capita/year by 2030. The available freshwater supply is ensured by surface water (56%) and groundwater resources (44%). The rate of use of the deep aquifers has reached 100% while the rate of shallow aquifers had already reached 108% (FAO 2009). Thus, Tunisia is becoming increasingly vulnerable to possible droughts in the face of increasing demands from all sectors for more water.

Irrigated agriculture consumes more than 80% of the available freshwater supply. The irrigable area reached 468,550 ha in 2012. The Irrigated Public Areas (IPBAs) cover 247,510 ha while the Irrigated Private Areas (IPRAs) cover 221,040 ha (Ministry of Agriculture 2013). Even though these areas represent only 8% of the agricultural land, they contribute to 35 % of the national agricultural production (Ministry of Agriculture 2008). Groundwater is the main resource for irrigation, supplying water for approximately 250,000 ha (FAO 2009). The success of irrigation in ensuring food security and improving rural welfare has been impressive, but the experience also indicates that inappropriate management of irrigation and unwise uses of the resources have contributed to environmental problems including excessive water depletion, water quality reduction, waterlogging, and salinization.

Methodology

Characterization of location

Located in the center of the country (Fig. 1), the region of Sidi Bouzid owes its economic and social development to irrigation. Known as a pastoral territory (semi-arid), the region receives an irregular average annual rainfall of 240 mm with a decreasing trend over the years (Fig. 2).

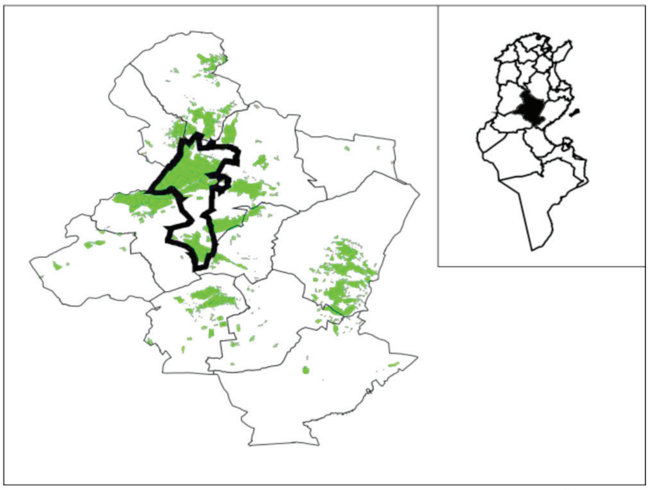


Figure 1: Location and irrigable land of Sidi Bouzid region.

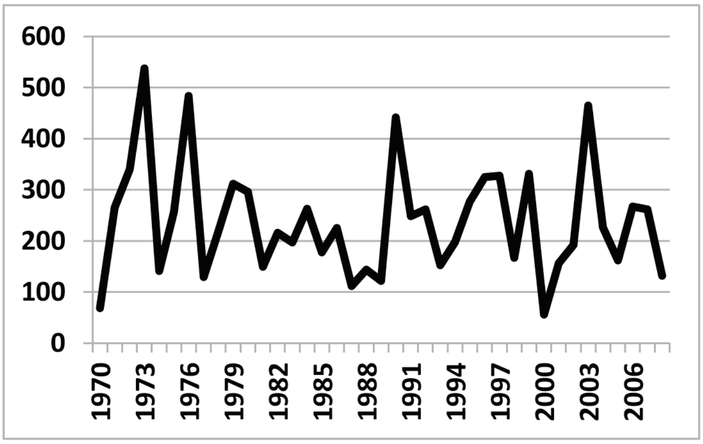


Figure 2: Rainfall in Sidi Bouzid region.

Given this climatic constraints, the government had relied on the groundwater in order to diversify the agricultural production and to improve the peasants' livelihoods. Hence, the first IPBAs had been created, in 1958, around a borehole. The experience was successful and it had motivated farmers to create their own water resources through drilling surface wells. This phenomenon increased until the numbers reached 10500 wells and 400 boreholes, notably increasing the irrigated area. In 2012, the potential irrigable area accounted for 46,530 ha which includes 5,730 ha of IPBAs (Ministry of Agriculture 2013). The irrigated sector generates up to 60% of the regional agricultural production and contributes up to 16% of the national production of vegetables (Ministry of Agriculture 2008). However, despite such development, significant difficulties remain in IPBAs as well as in IPRAs.

Certain public irrigation channels have got damaged resulting in water losses up to 40% (Ministry of Agriculture 1995). The use of the flood irrigation system is dominant leading to significant additional water losses. The proliferation of surface wells increases the overuse of the groundwater that is reflected in folding back of water table by an average of 30 cm/year and in an increase of the salinity of the water and soils (Ministry of Agriculture 2006). In 2009, water withdrawals rate of the shallow aquifers reached 132%.

Sidi Bouzid West represents the real landscape of the irrigation development in the region. In fact, beside the ancestral practice of the flood irrigation around Elfakka river, the first public irrigated area was created in this region in 1958. The outstanding development of the irrigation activities occurred because of sharp increase in the number of wells, reaching 2600 units in 2009 (which was 25% of the total number of wells in the governorate). The area of Sidi Bouzid West is 42,712 ha, which represents only 9% of the arable agricultural land of the region. In 2009, the potential irrigable land reached 9,262 ha, which represented 27% of the land of the region, divided between 1,462 Ha as public irrigated area and 7,800 ha as private irrigated area. The area accounts for 37% of the forage, 29% of the cereals, and 27% of the vegetables production (Table 1).

Table 1: Importance of region (2009) Sidi Bouzid West

	Sidi Bouzid	Sidi Bouzid West	%
Potential of the irrigable land(ha)	33853	9262	27.36
Cereals production (T)	12500	3650	29.,20
Forage production (T)	6700	2500	37.31
Vegetables production (T)	12420	3350	26.97

Source: CRDA Sidi Bouzid (2010).

Survey approach and data collection

In 1985, most of the agricultural areas of Sidi Bouzid West were declared as prohibited or areas for irrigation because of the excessive abstraction of the groundwater resources. Despite this legal prohibition, farmers continued to drill wells. For this reason we decided to implement a monitoring process to study the impact of these unwise practices on the availability of the water and the farming system. In 2004, we selected 26 irrigated farms with the support of the technical staff of the Regional Commissariat of Agricultural Development (CRDA) of Sidi Bouzid. We carried out a detailed surveys regarding the wells, the operational pumping plant, the irrigation system and all the technical and economical parameters of the cropping system during the agricultural season of 2003. Afterwards, we returned to the same farms in 2008 and in 2012 in order to gather the required data regarding the cropping years of 2007 and 2011.

Results

Households and dynamic of the cropping system

The total area of the study site was 187 ha of which 134 ha were irrigable. All the interviewed farmers were landowners. The average age of the farmers was 57 years. Six farmers (23%) were illiterate and 14farmers (54%) had the primary school profile. The average of the households' size was around six members, three of them did the most of the work of the farms. In 23% of the surveyed farms, all the agriculture activities were done by the family workforce.

The average of the arable land per farm was only 7.2 ha with 5.64 ha as potential irrigable land. A total of13 farms were irrigated totally. Some 14 farmers had less than 5 ha of irrigable land. The number of the surveyed wells was 32. All the farmers practiced flood irrigation system and only 8 farmers used sprinkler or drip irrigation for some crops (cereals and vegetables). The cropping system was dominated by olive trees, which occupied more than 80% of the area. Due to low availability of land, farmers were constrained to practice intercropping to satisfy their food needs and those of their animals and to put the surplus in the market for the required cash flow.

The potential irrigable area increased from 2003 to 2011. The irrigated area increased from 2003 to 2007 while it decreased from 2007 to 2011(Table 2).

Table 2: Dynamics of the cropping system

	2003	2007	2011	Average
Irrigable area (ha)	117.95	137.75	146.75	134.15
Irrigated area (ha)	185.2	201.2	190.5	192.3
Intensification rate (%)	157	146	130	144
Olive trees (ha)	108.2	137.35	141.25	128.93
Cereals crops (ha)	31.5	8	1.5	13.66
Forage crops (ha)	8.25	15.85	10.25	11.45
Horticulture crops (ha)	37.25	40	37.5	38.25
Total crop area (ha)	77	63.85	49.25	63.36

The irrigable areas increased by 24% between 2003 and 2011 because of the cleaning of wells and/or the drilling of new wells. It shows that the irrigator usually needs more resource to implement its cropping system without taking into account the severity of the overuse of the groundwater. Nevertheless, this increase of irrigable area did not lead to an increase of irrigated area. In fact, the irrigated area showed only slight increase, around 5%, but the intensification rate decreased from 157 in 2003 to 130 in 2011. The cropping system dynamics showed that there was an increase in the area of the olive trees by 30% between 2003 and 2011, which proves the importance of this activity. Also, farmers grew vegetables because of its high value. The area of cereal crops decreased while that of forage increased because of the introduction of rearing of the dairy cows.

Monitoring the wells and the water consumption

In 2003, the number of wells was 32. Six farmers had already two wells. Some 19 wells were created in the 1980s . Between 2003 and 2011 two wells were abandoned and three new wells were created. Hence the number of wells in 2011 was 33. Given the drawdown of the groundwater table and the decrease of the flow rate, farmers cleaned out their wells. The results showed that 29 wells were cleaned at least once and 14 wells were cleaned 3 to 10 times. This practice increased notably the depth of the wells. In fact, the average depth of the surveyed wells shifted from 49 m in 2004 to 63 m in 2012. Already, 21 wells reached illegal depth by exceeding 50 m. Some 16 wells were created without getting official authorization.

By measuring the flow rate and the salinity we confirmed the overuse of the groundwater. Through the operation of cleaning out, the rate of flow was not really improved because it shifted from 3 l/s in 2004 to 3.2 l/s in 2012. On the other hand, the water salinity increased by 1.1 g/l. In fact the water salinity increased from 3.1 g/l in 2004 to 4.2 g/l in 2012.

In 2003, only five wells were run on electricity. Between 2003 and 2011 the government had allowed many farmers to get electricity in their farms. Hence, in 2011, the number of wells using electric energy shifted from 5 to 19. This might have decreased the pumping costs but did not result in wise water withdrawals.

Regarding the water consumption (Table 3), the results showed that the farmers kept the same level of water withdrawals during the period 2003-2011, around an average of 13,192 m^3 per farm. In fact, the average consumption per farm was 13,715 m^3 in 2003 while it reduced to 12,259 m^3 in 2011. The vegetables were the biggest consumers of irrigation. However, the consumption decreased from 2003 to 2011. The olive trees consumption on the other hand increased.

Table 3: Evolution of the water consumption

	Unit	2003	2007	2011	Average
Olive trees	m3/ha	621	784	1056	820
Cereal crops	m3/ha	1506	2056	2011	1857
Forage crops	m3/ha	1380	1239	1077	1232
Horticulture crops	m3/ha	6227	5518	3421	5055
Consumption/farm	m3	13715	13602	12259	13192

***Economic* analysis**

In terms of economic analysis (Table 4), the value of the production per farm increased from 2003 to 2011. The olive trees remained the principal crop providing an average of 38% of the total production. The running costs per farm also increased in the period. The irrigation charges accounted for 40% of the total running costs.

The farm revenue however increased in the period 2003 to 2011. This improvement was mainly due to the increase of the prices of olive and vegetables in the country. In 2011, the average running costs of the pumping water per m^3 was 0.224 TND. Between 2003 and 2007 this price had increased by 72% due mainly to the increase of the fuel price which increased by 110%. This price was 0.328 TND/m^3 in the case of diesel pumping plant but only 0.150 TND/m^3 for electric pumping plant.

Farm modelling and simulation

The farming system modelling using mathematical programming is a long tradition in the agricultural economics (Glen 1987). The linear mathematical programming approach has been predominant in this domain. These models are however seriously constrained to reproduce the choices at the reference year. Positive Mathematical Programming (PMP) allows to reproduce automatically the observed situation. The principles of this method are based on three ideas. The

Table 4: Economic results (Tunisian Dinar,TND, 1TND=0.603$US)

		2003	2007	2011	Average
Olive trees	Production	268	681	821	590
	Total cost	87	165	261	171
	Irrigation	73	159	237	156
Cereal crops	Production	535	436	667	546
	Total cost	237	287	482	335
	Irrigation	178	417	450	348
Forage crops	Production	1045	542	502	696
	Total cost	153	237	334	241
	Irrigation	163	251	241	218
Horticulture crops	Production	2396	2254	3342	2664
	Total cost	1102	1470	1094	1222
	Irrigation	735	1120	766	874
Price of water per m3		0.118	0.203	0.224	0.181
Revenue per farmer		2324	1314	4148	2595
Total value of production per farm		5767	7229	10645	7880
Value of olive product per farm		1201	3387	4392	2993
Value of crop products per farm		4566	3842	6253	4887
Total charges per farm		3443	5915	6497	5285
Irrigation charges per farm		1118	2648	2692	2153
Share of irrigation charges		38	42	42	40.7

first is the translation, in the objective function, of technical constraints faced by the producer that are difficult to be expressed by the modeller (forced labor, for example). The second idea is to consider the observed data corresponding to an optimum producer. This justifies the fact that the observed data are used to calibrate parameters introduced into the model. The third idea of PMP is the introduction of non linearity in the objective function via a cost function or production function. Based on these principles and given the descriptive results above, we have reproduced the observed farming system through developing the following model:

$$\textbf{Max} \quad Z = \sum_i \mathrm{Pr}od_i * X_i - \left[\sum_i Chrg_i * X_i + \sum_i EauQ_i * X_i * Peau \right]$$

Subject to

$$X_{oliv} = Sirrig_{oliv}$$

$$X_{cereal} \geq Sirrig_{cereal}$$

$$\sum_i X_i \leq \sum_i Spirrig * Int$$

$$\sum_i EauQ_i * X_i \leq EauT$$

$$X_i \geq 0$$

where ***Z*** is farmer's profit***, Prod*** is the production value per hectare; ***Chrg*** is the running costs per hectare; ***EauQ*** is the water consumption per hectare; ***Peau*** is the water price per m^3; ***Sirrig*** is the observed irrigated area, ***Spirrig*** is the potential irrigable area per farm; ***EauT*** is the observed available water per farm during the cropping year, it equals to the observed water consumption; ***X*** is the vector of activities' areas; ***i*** the observed activities: production of olive trees, cereal crops, forage crops and horticulture crops.

The objective function tends to maximise the farmer's profit (Z). As the area of olive trees must not change during the optimizing process, the first constraint indicates that the area of this activity is fixed at the observed irrigated area. The second constraint meant that the area of the cereal crops' activity could not decrease under the observed irrigated area. The third constraint indicates that the total area of the expected irrigated activities does not exceed the potential irrigable times the intensification rate. The last constraint meant that the total water consumption of the expected activities does not exceed the observed available water.

By developing the model above, we have tried to reproduce the farming system as depicted through the results of the surveys. The comparison of the observed values and those of the optimal solution (Table 5) showed that the model reproduces the same production choices.

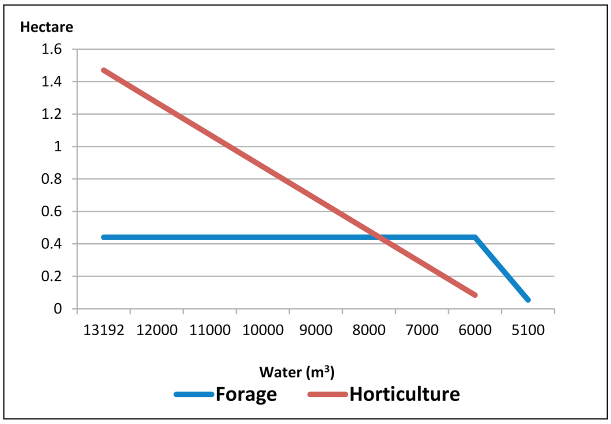
Table 5: Comparison of the optimal solution and the observed values

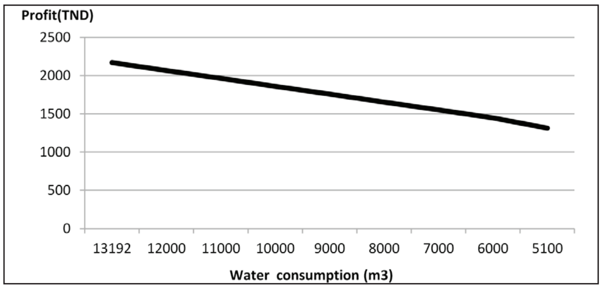
	Observed values	Optimal solution
Olive trees (Ha)	4.96	4.96
Cereal crops (Ha)	0.52	0.52
Forage crops (Ha)	0.44	0.44
Horticulture crops (Ha)	1.47	1.47
Water consumption (m3)	13192	13006
Revenue (TND)	2595	2170

The optimal revenue represents 84% of the observed revenue. We have simulated three scenarios. The first one addressed the water scarcity issue by simulating an expected decrease of the water availability. The second treats the increase of the water price and the third analyses the farmers' decision to intensify the land use.

Impact of decreasing the water availability : Given the overuse of the groundwater, we expect that water availability will decrease in the future and farmers will have to manage their cropping system. The simulation of this scenario (Fig. 3) showed that the farmer will reduce the area of the horticulture crops first. When this availability decreases to rreach under 6000 m^3 the farmer will reduce also the area of the forage crops (Fig. 3a). The minimum of the water availability that allows farmer to continue the irrigation of the olive trees and the cereal crops is expected to be 5100 m^3.The impact of decreasing the water availability will affect negatively the farmers' profit (Fig. 3b). The minimum availability of water allowed the farmer to gain the profit of 1314 TND, which represents only the half of the currently observed profit.

Impact of increasing the water price: By starting the simulation at the lowest price of water, 0.118 TND/m^3, as computed in 2003, the results showed that farmers maintained the observed activities and the water consumption will be at its highest level (Fig. 4a). By increasing the

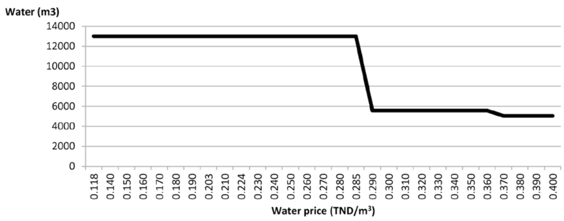


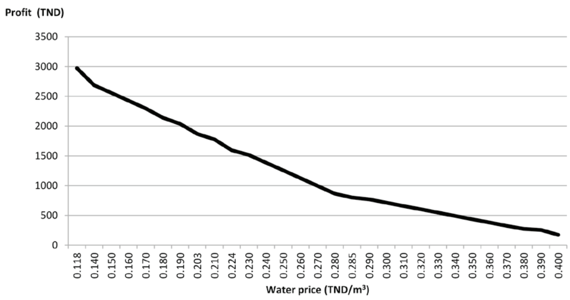


(a): Impact on the irrigated area **(b):** Impact on the farmers' revenue

Figure 3: Scenario of decreasing water availability. Impact on irrigated area and farmer's revenue

water price to 0.285 TND/m^3 the cropping system did not change but the revenue decreased to 801 TND, which represents only the third of the observed current revenue (Fig. 4b). This result confirms the importance of the irrigation's expenditures in the total running costs. When the price of water exceeded beyond this value, the model showed that farmers will abandon the horticulture crops. Hence, the water consumption would decrease by more than 50%. When the price reaches 0.370 TND/m^3 the model shows that farmers will practice only the olive trees and the cereal crops that would permit revenue of only 326 TND.





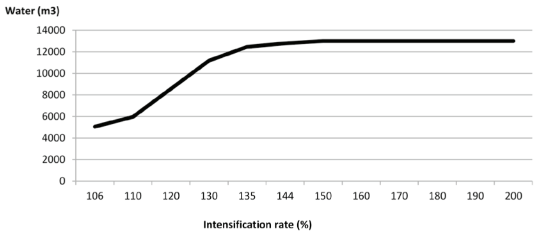
(a): Impact on the water consumption **(b):** Impact on the farmers' revenue

Figure 4: Scenario of increasing the water price; impact on water consumption and revenue.

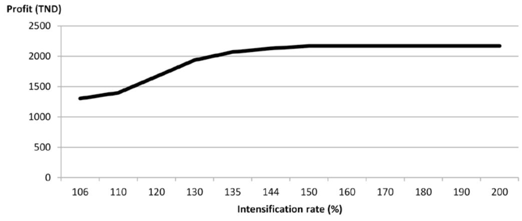
Impact of increasing the intensification rate

When farmers decides to use only the available potential irrigable area to grow the olive trees and to produce cereals as stated by the first and the second constraints of the model, the basic intensification rate would be at least 106%. This intensification rate allowed farmer to gain the revenue of 1304 TND which represents only the half of the observed revenue. By increasing the intensification rate the optimal solution showed that the farmers will grow firstly the horticulture crops. This decision was justified by the importance of the value addition provided by this activity.

When the intensification rate reached 135%, the model showed that the area of the horticulture crops would reach the observed area (1.47 ha). When the intensification rate reached 140% the farmers will have the possibility to introduce the forage crops. At the observed intensification rate (144%) the optimal solution joint corresponds to the observed cropping system. Thereafter, any further increase in the intensification did not have any impact on the cropping system due to the constraint of water availability.



(a): Impact on the water consumption



(b): Impact on the farmers' revenue

Figure 5: Scenario of increasing the intensification rate. Impact on water consumption and revenue.

The increase in the intensification rate increases the water consumption (Fig. 5a). At the basic level of intensification rate the water consumption was at the lowest (5057 m^3) which represents 40% of the current consumption. However, the model showed that horticulture crops will enhance the water consumption by 147% in order to reach 95 % of the current consumption. The introduction of horticulture crops also allowed an improvement of the revenue by 59% that raised farmers' gain at 2070 TND which represents 80% of the observed gained revenue (Fig. 5b). The introduction of the forage crops did not have strong impact on water consumption and the farm revenue.

These results confirm that the intensification of the land use through the enhancement of horticulture crops results in an overuse of groundwater even though it improves the farmers' revenue. On the other hand, the introduction of rearing of dairy cows did not appear competitive and may disappear in the future.

Conclusion

Irrigation, based mainly on the groundwater withdrawals, remains one of the main pillars of the dry land development. However, the water scarcity is increasing, particularly within the context of the climate change. Hence, the inefficient and unwise use of water threatens livelihoods of farmers who directly depend upon access to groundwater. In Sidi Bouzid, a typical dryland region, the irrigation development has already led to the drawdown of the groundwater table. The overuse of this resource and the negative impacts on water and soil quality, started since 1980s, is of concern to framers in securing their livelihoods. Monitoring 26 irrigated farms from Sidi Bouzid, for three cropping years (2003, 2007, 2011), confirmed the importance of the groundwater depletion and the increase of the water salinity. There was a decrease in cropping intensity. The olive trees remained the principal component of the farming system. However, farmers gave more importance to the vegetable crops despite their huge water consumption. Irrigation was the main contributor to the total running cost of the farms. Between 2003 and 2011, the price of the pumping water increased by 90% mainly due to the increase of the fuel price. Simulation studies regarding the decrease of the water availability, the increase of the water price and the increase of the land intensification showed that farmers have to adapt their cropping system accordingly. In each scenario their revenue may decrease substantially. Vegetable production remains the main activity affecting the water consumption and the revenue. Unfortunately, farmers did not have any options to better manage their cropping system in order to cope with the water scarcity and to preserve their livelihoods. Hence, given the alarming situation, irrigation and water resource planners and managers will need to pay more attention to the expansion of groundwater irrigation, and the sustainable use of this finite and unseen resource.

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Experiences of governments/JICA/Tottori-University tripartite cooperation in capacity development on dry land agricultural technologies

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Abstract

Dry land agriculture faces multi-faceted challenges including *inter alia* scares water resources for crop and livestock production, accompanying risks of land degradation, and attendant socio-economic instabilities. The governments of countries with sizable dry land areas have been struggling to cope with adverse effects of inappropriate irrigation practices while supporting livelihoods of the people. In this fight, international cooperation has always been a part of it, and human resource development and institutional capacity building to ultimately assist producers with improved technologies are among the most important components of this cooperation. In this context, some thirty, largely African and middle-eastern countries have been working with Japan International Cooperation Agency (JICA) and Tottori University (TU) of Japan in training their human resources in dry land agriculture technologies in the past twenty years, by way of 3-4 month long training workshops on land degradation evaluation, desalinization techniques, comprehensive water management, farmer support activities, etc. However, training a few technical personnel cannot easily meet the requirements of a country and not all the international development agency's experiences are readily applicable to the realities of diverse country situations. Therefore, the author is analyzing the experiences of this tri-partite collaboration in capacity development in dry land agriculture to identify successful features and challenges for technical cooperation endeavors. Suggestions include that networking of ex-participants as change agents would be an encouraging mechanism for further promotion.

Introduction

The world is experiencing continued human and livestock population growth, and agricultural production to meet food and feed demands is increasingly placing pressure to the limited land and water resources, in particular in the arid and semi-arid areas. As the desertification situation is not easing, we must accelerate more efficient use of limited natural resources without causing soil and land degradation.

The UNCCD has advocated that, "*The UNCCD is particularly committed to a bottom-up approach, encouraging the participation of local people in combating desertification and land degradation. The UNCCD secretariat facilitates cooperation between developed and developing countries, particularly around knowledge and technology transfer for sustainable land management* (UNCCD 1994)." In addition, desertification is obviously worsening due to climate change (Millennium Eco-system Assessment – Desertification Synthesis 2005), as manifested in complicated recent incidences in the horn of Africa and elsewhere.

With these pressing situations as the premise, some thirty, mainly sub-Saharan Africa and middle-eastern countries have been working, through Training Workshops, with Japan International Cooperation Agency (JICA) and Tottori University (TU) on human resources development and institutional capacity building in technologies that will contribute to successfully facing the aforementioned challenges.

The first round of this tri-partite (or multi-partite) cooperation started in 1989, five years before UNCCD was established, and the year 2012 has marked the 24th year of this endeavor. The workshop was initiated in as early as 1989 based on TU's foresight on the prevailing conditions of the world's dry areas and the technical base TU had acquired over the years in dry-land agriculture and water resources management through extensive research activities carried out on sandy soils of Tottori and overseas. The total number of persons that took part in these workshops, over these years, now counts 223, and the countries that sent more than 3 participants to the Workshop is thirty (Table 1).

Table1: List of participating countries with more than 3 participants in 1989-2012. The number of participants are in parenthesis

Sub-Saharan Africa:

Burkina Faso (7), Chad (3), Ethiopia (8), Kenya (18), Niger (6), Sudan (5),

Swaziland (3), Tanzania (8), Zambia (6), Zimbabwe (7)

Middle East & North Africa:

Algeria (6), Egypt (16), Iraq (4), Jordan (3), Morocco (3), Oman (4), Palestine (3),

Saudi Arabia (9), Syria (3), United Arab Emirates (3), Yemen (6)

Asia: Afghanistan (6), China (11), Pakistan (6)

Latin America & the Caribbean:

Bolivia (3), Brazil (6), Chile (5), Ecuador (3), Haiti (6), Mexico (10)

The workshops have so far been conducted in five different phases (Table 2), each with some changes in training modules. The main modules have by and large remained the same and include: 1) water resources management; 2) on-farm water management; 3) crop, soil and fertilization management; 4) irrigation and drainage facilities management; 5) environmental impact assessment (EIA), 6) geographic information management; and, 7) rural management (JICA 2012). The evolution of the workshop design occurred in accordance with the requirements expressed by the participants themselves and through the dialogue among stakeholder governments and JICA/TU.

However, training small numbers of individuals will not meet the vast requirements of countries and international development agency's experiences are not readily applicable in diversified field and socio-economic conditions. In this light, the objective of the present study was to analyze the experiences of this tri-partite technical cooperation project (training) for successful features in terms of dissemination to wider range of stakeholders and challenges for future considerations.

Table 2: Five different phases of the Training Workshops, 1988-2012

Phase 1 (1989-1998):	"Water Resources Development and Its Use in Arid Regions"
Phase 2 (1999-2003):	"Irrigation Water Resources in Arid and Semi-arid Region and EIA for Sustainable Development"
Phase 3 (2004-2008):	"Irrigation Water Resources in Arid and Semi-arid Region and EIA for Sustainable Development-2"
Phase 4 (2009-2011):	"Appropriate Management of Land and Water Resources for Effective Utilization in Arid & Semi-arid Regions"
Phase 5 (2012- on):	"Appropriate Management of Land and Water Resources for Sustainable Agriculture in Arid & Semi-arid Regions "

Materials and methods

The present research is chiefly a desk study, supplemented by field studies to collect information through direct interviews of selected former participants in Ethiopia and Sudan. These countries were selected chiefly because the numbers of ex-participants was relatively larger than other countries, but also because there were other purposes to visit the two countries.

The main features of the training workshop are as follows:

l. Workshop duration in general has ranged from 3 to 4.5 months
m. Participants are engaged in land and/or water resources management as profession;
n. They are recommended by their own government;
o. The number of participants in each workshop ranged from 8 to12 persons;
p. There are class-room lectures, field practicals, observation tours to large-scale projects, and discussion sessions; and,
q. Participants, in the end, write an Action Plan (AP) to address problems in their countries and to serve as the basis for experience-sharing with colleagues and other stakeholders back in the country.

As the training workshop over the years has produced various documentations written by participants themselves during their stay with TU, they were used as the main source of data and information. Questionnaires were also sent to 83 ex-participants via email, and their replies were used to obtain results. (As email addresses were available only from 2004 group onward, questionnaire was sent to those groups only.)

Statistical analysis was not performed for the present research as the sample size so far has remained small; but some trends were captured from similar cases and discussed hereunder. The major limitation of this research, which derives data and information from a development project (training), was that an objective impact assessment based on comparison between 'with' and 'without' cases was not possible. The research heavily relies on replies of ex-participants as to whether they carried out AP they made during Japan-phase, and with a few exceptional cases, no verification was conducted to confirm authenticity of their reply.

The main focus of the research is to find out whether an AP is realized, if so to what extent, and whether the experience-sharing is taking place to disseminate important concepts and/or technologies to relevant personnel. The questionnaire sent out consisted of both general questions, which the ex-participants could answer freely, and specific questions by showing sample answers to choose from, such as: “*What do you remember about JICA Training, in general*,” “*How did you (try to) work on your AP? Who helped you?*” “*How much funding did you get to implement your AP?*” and “*What did you do: Workshop/Seminar, Debriefing Meeting, a Project?*” Open-ended general questions were asked as not to constrain free expression of their ideas.

Results and discussion

While data not presented here, the overall rating of the workshop by the participants at the end of the program was largely positive (expressed as “successful,” “satisfied,” “useful,” etc.) and the most frequently expressed suggestions for future consideration were that the program obviously tried to cover too wide a range of subjects and time was not enough. A few people, however, expressed an opposite view that the program was both compact and diverse and gave them lots of insights.

Table 3 presents actions taken by the ex-participants on their Action Plan (AP) and how, after they were back in their countries, together with other information so that possible relations between the action and attendant conditions can be captured. A total of 28 ex-participants out of 83 replied, thus the reply rate was 34%. By “Years after Training,” the 28 ex-participants who replied ranged from 1 to 12 years.

Table 3

Based on the replies, the overall rate as to whether AP was fully or partially implemented was 89% (or 25/28), indicating the enthusiasm of ex-participants to follow their own AP. However, a closer look at the timing and contents revealed that, in most cases, a few information-sharing workshops were conducted by the ex-participants inviting their immediate colleagues within 2-4 months after their return. Since information-sharing workshop is also a part of the AP, the overall rating for AP implementation, calculated this way, ends up to be high.

Now, based on the timing column (expressed “When”) of Table 3, only five cases out of 17 (29%) are “continuous.” So, while the short-term implementation rate of the AP appears high, when sustainability point of view is incorporated, it will be a different story. To see if there is any factor contributing to the length of commitment, let us have a look at the “continuous” cases in more details. Out of the 5 “continuous” cases, 3 are professors or teaching staff; it is natural that they disseminate acquired knowledge to their students continuously. The remaining 2 cases are conventional governmental posts (No. 10 from Kenya and No. 14 from Sudan), and again it is worth examining the two cases in more detail.

For both No.10 (Kenya) and No.14 (Sudan) cases, implementation of AP was supported by an on-going project which the ex-participant is somehow engaged with. There was an interaction with other ex-participants as well. The Case No.10 is actually closely linked with a large national project (NIB 2013) that transfers irrigation management to farmer’s association (WUA). In that context, the AP prepared by the ex-participant was incorporated into the institutional work plan by the senior management of his organization, making his AP continuous (Box-1).

Box-1. A case from Kenya: I attended the Course on Irrigation Water Management in Arid and Semi-Arid Lands and EIA, and the topics covered and the interactions we had with industry players were useful and informative. I feel change in that I became aware that the things I thought were not possible are actually possible. The training made me realize there was so much work needing to be done and I had a responsibility to initiate and influence .policy

I shared my AP with CEO and other management staff, after which a task team was formed to implement my AP for the Institution. The main part of my AP is capacity building of irrigation Water Users Associations, farmers, and staff of my organization on participatory approach to irrigation management and transfer of functions for sustainability. I know another ex-participant of the same Course, and we have been working in project teams of (the organization. We work on some projects financed by a donor. (Participant of 2004

As for Case No.14 (Sudan), the ex-Participant prepared an AP about water quality management as he works for the State Water Corporation (SWC). He first held training workshops for engineers and technicians in March and April 2010. Since a donor-supported project is going on to strengthen SWC, he receives their supports and can continuously hold workshops for field engineers and villagers. The workshops are on community managed water supply systems and water-borne diseases. Here too, his AP is somehow institutionalized and his commitment to disseminate gained knowledge is sustained.

To look at a different case regarding how the ex-participant tried to disseminate to the colleagues and farmers the idea he gained in the Workshop, an ex-participant of Sudan (No.13) organized 2 seminars for irrigation engineers, technicians and laborers on how to increase water use efficiency. As he did not get funding from his organization to implement his AP (mainly about field study), he used his own pocket money on the minor expenses incurred on the seminar. His answer to the questionnaire indicates that, he wanted to keep his words to his mentors in TU and his fellow participants. In this case, some sort of psychological link was working.

Box-2. A case from Sudan: The Workshop helped me very much. I did many things after I came back. I held a workshop/seminar in 2010 on how to increase water use efficiency for 4 engineers for 3 days, and another for technicians and laborers on gate operation for 1 week. I did it because it was agreed upon during my training in Japan. As I didn't get budget from .my Ministry, I paid the costs myself. As I held them in Khartoum, it didn't cost me a lot

I remember that I learnt about water resources, how to design canals, control and distribute water to the fields and increase water use efficiency. I had heard about GIS but didn't really know it before. Now we can fix coordinates among different stations using GIS. I learned how to use irrigation facilities and instruments to maintain facilities. I feel I have (improved myself. (Participant of 2009

As seen in Table 3, CROPWAT and GIS were spontaneously mentioned by 6 ex-participants out of 28 (21%) as "useful." They use this FAO-provided free software (FAO 2013) in teaching their colleagues the importance of water saving through systematic assessment of water requirement for each crop, indirectly implying that the message the Workshop tried to convey to the participants was well received by this group (not less than 21%). GIS is also a tool that assists in the rational planning and monitoring on appropriate water use. These can be taken as an indication that once an appropriate tool is made available, dissemination of an important idea relevant to the dryland agriculture gets accelerated. Use of simple and freely accessible tool seems to play as a catalyst for successful human resources development initiative.

Box-3. A case from Sudan (2): I'll never forget the training in Japan. It was very useful containing a wide range of Modules, which helps on proper understanding of planning and optimum use of water. I felt change in myself like I was born again. In terms of concept of .work, I feel change in my commitment to the time and my search for anything new

I worked hard on my AP. I held some in-house workshops with supports from the on-going project. This week the Ministry of Agriculture of Gezira State will organize a workshop on rice with JICA's support, and I will give lectures. I use and teach CROPWAT to estimate crop water requirements for irrigation scheduling. I also want to make bio-char (natural fertilizer) taught at TU. The manager of my project tells me to do it in the demonstration field. There will be significant impacts on farmers as they are the ones who will apply the things I teach. They will know how to optimally use water and save water resources. (Participant of (2012

From Table 3, it is observed that the response rate to the questionnaire drops sharply after 4 years of the Workshop (response rate for 2012, 2011, 2010, 2009 groups being 6/12, 4/10, 5/9, 4/12 whereas that for 2008, 2007, 2006, 2005 and 2004 groups are 2/8, 2/8, 0/5, 1/11 and 2/8 respectively), implying that the level of excitement right after the workshop may go down after four years or so. As some ex-participants have suggested, provision of a refresher course for them may serve as an effective booster, revitalizing the once sensitized mind for a higher level of sustained motivation.

As to the interaction with other ex-participants, while 21 people out of 28 (75%) have said that they know one or two other ex-participants (Table 3), the majority of those directly interviewed expressed surprise when they heard names of more ex-participants. They opined that it would be very useful knowing contact details of others as they could exchange ideas using a wider network for their activities. The ex-participant of the Case No.12 rightly replied that bringing about change in the organization can not be achieved alone but requires a critical mass that serves as change agent.

While available information is limited, a few ex-participants mentioned "punctuality" and "hard-work" of the workshop staff and general public as a good memory, even after many years; some even mentioned to the effect that development of a well-managed system may have something to do with such good values filling the community. In the light of an argument that short-term overseas training courses may not be a cost effective way for technical cooperation, this aspect, as indicated by the few ex-Participants this time, seems to deserve more attention.

Conclusions

Evaluation of international workshops focusing on technical matters to address issues closely related to desertification - a long-term challenge - needs a medium-term monitoring, despite the

				Action Plan (AP) proposes:			Implementation of AP			Implementation of AP (how)	
No.	**Country**	**Year of Training**	**Year after Training**	**Workshop/ Seminar**	**Start a separate project**	**Technical Area**	**Carried-out partially/ only WS**	**Carried-out fully**	**When**	**Support from on-going project**	**Interacted with other ex-Participants**
1.	Ethiopia	2001	12	x	x	Water use efficiency	Teach students		Continuous		x
2.	do.	2002	11	x	x	Irrigation technology	Teach students		Continuous		x
3.	do.	2007	6		x	Irrigation methods	x		After 2 months		x
4.	do.	2012	1	x	x	Irrigation system	x		After 2 months	x	x
5.	do.	2012	1	x	x	Watershed management	x		After 2 months		x
6.	Burkina Faso	2009	4	x	x	Watershed management	x			x	x
7.	do.	2010	3	x	x	Water resources management	x			x	x
8.	do.	2010	3	x	x	Land & water management	x				x
9.	do.	2011	2	x	x	Water and soil management	x		Right after return		x
10.	Kenya	2004	9	x	x	CD of WUA		x	Continuous	x	x
11.	do.	2007	6	x	x	Irrigation infrastructure	x			x	x
12.	do.	2010	3	x	x	Land & water resources management	x		After 1 year		
13.	Sudan	2009	4	x		Efficient water use		x	After 3-4 months		
14.	do.	2011	2	x		Water quality management		x	Continuous	x	x

				Action Plan (AP) proposes:			Implementation of AP			Implementation of AP (how)	
No.	Country	Year of Training	Year after Training	Workshop/ Seminar	Start a separate project	Technical Area	Carried-out partially/ only WS	Carried-out fully	When	Support from on-going project	Interacted with other ex-Participants
15.	do.	2012	1	x		Efficient water use	x		After 2 months	x	
16.	Afghanistan	2009	4	x		Field water management		x			x
17.	do.	2010	3	x		Field water management					x
18.	Algeria	2005	8	x	x	Use of treated waste-water	x		After a few months	x	x
19.	do.	2009	4		x	Water harvesting					
20.	Zimbabwe	2011	2	x	x	Water pollution control	x		Right after return		x
21.	do.	2012	1	x		Improved irrigation scheduling	x				x
22.	Cameroon	2012	1	x		Agric. facility management	x		After 2 months		
23.	China	2008	5		x	Land and water management	x		Immediately after return	x	
24.	Iraq	2012	1	x	x	Hydroponics	x		After 2 months		x
25.	Malawi	2008	5		x	Soil management	Teach students		Continuous		
26.	Pakistan	2004	9	x	x	Irrigation infrastructure	x				x
27.	Yemen	2010	3	x		Land and water management					x
28.	Zambia	2011	2	x		Capacity development	x			x	x

fact that often very favorable results are obtained from an immediate evaluation. Since the main interest of such an initiative does not stay within the domain of individual capacity development but it aims at going over to institutional capacity building, a closer attention to the monitoring of sustained commitment in the field is worthwhile.

Participants having close links with on-going initiatives like development projects would have relatively easier access to resources when they intend to implement their AP. As seen in cases No.10 and No.14, when individual capacity development is adequately linked to the institutional initiative, the gained knowledge is more systematically disseminated. This aspect can be positively considered in the selection process too.

This view notwithstanding, the majority of participant is rather apart from such existing initiatives and needs separate consideration. While the ex-participant of Sudan from the SWC (No.14) was supported by an on-going project for his AP, he was also able to obtain funds from an IFAD grant through his supervisor to support his activities for community people. So, field level information sharing is vital and network building among ex-participants also seems an area that requires more focus.

Unless network is in place connecting ex-participants with each other for active exchange of ideas and sharing information as to the progress made and problems being faced, individual capacity building will not lead to institutional development in terms of technologies necessary for dryland agriculture. Networking of like-minded ex-participants would permit development of a critical mass. If not exactly in the same context, the necessity of linking capacity development initiatives is emphasized in the World Bank report (World Bank 2005).

Considering the magnitude of the issue the initiative like this workshop aims to address, it is not practical to believe that problems will be solved within a few years' framework, thus it would be more appropriate for all parties involved to upgrade the level of dialogue on the progress of the AP in the field. Network building and strengthening can be done through sharing lists of ex-participants or holding refresher course, maybe in the field.

An important limitation of the present research was that comparison between cases where 'AP was carried out' and 'AP not carried out' to extract factors contributing to the difference was not possible, because ex-participants who could not try their AP apparently did not answer the questionnaire. Thus, further studies are necessary to clarify this point. Efforts are required foremost to increase the sample size by collection more information, in particular from those who couldn't put their AP into practice. To know if there is any causal relationship between spontaneous learning and something like cultural shock (and the length of stay in a foreign community) can be a separate research subject.

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Table 3: Summary of actions taken as on Action Plan by ex-participants who responded to the questionnaire

Contribution of livestock to the livelihood of local communities in the dry coastal zone of Western Desert in Egypt

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Abstract

The coastal zone of Western Desert in Egypt is a hot and dry area. Raising livestock, especially sheep and goats, is historically the main socioeconomic activity for the local communities (Bedouin) there. Three agro ecological regions are recognized in the zone: the rain-fed area with communal grazing in the West, the newly reclaimed land with irrigated farming in the East, and the desert oases in the South (Siwa). The area has witnessed a long drought incidence from 1995 to 2010. A field survey was therefore carried out with 182 livestock breeders to assess the socioeconomic vulnerability of the local community under the prolonged drought conditions and the role of livestock in sustaining their livelihood. Livestock contribution to the income of the local community in the rainfed region differed significantly with flock size (28 % for the small size, up to 80 % for the large size flocks). The contribution in the newly reclaimed lands was related to farm size (58 % for small farms of < 2 acres and up to 71% for large farms of >35 acres). Share of small ruminants in the livestock income was 95 % for the small farms and 84% for the large farms there. Livestock contribution to the income of desert oasis ranged from 6% for small holders to 46% for large holders. Goats contributed significantly to the nutritional status of the families through domestic consumption of both meat and milk. Off–farm activities contributed moderately to the income of the small holders in the three regions and to the medium holders in the oasis and the newly reclaimed region (22-38%). Crops (mainly cereals) and fruit trees contributed significantly to the income of oasis communities and moderately to the small and medium breeders in the rainfed area and the newly reclaimed lands.

Introduction

The coastal zone of Western Desert (CZWD) in Egypt extends over 500 km from Alexandria in the East to Libyan border in the West, with <150 mm of rainfall and >37°C average summer temperatures. It is historically hot dry pastoral area. Raising sheep and goats, beside some camels, is the main socioeconomic activity for the livelihood of the local communities (Bedouin) there. The zone had witnessed major changes over the last decades, namely demographic growth, urbanization, touristic development and land reclamation in the eastern part. More recently the zone has faced a long drought period from 1995 – 2011, with low erratic rainfall (< 150 mm annually).

The area consists of 3 distinct agro-ecological regions (Fig. 1).The rain-fed area (West) is characterized by transhumant livestock system on natural ranges, with limited cropping activity - mainly barley for animal feed (as grains and stubbles in normal years or as a pasture in dry years) and orchards. The eastern region had recently adopted a major agrarian reform in the form of newly reclaimed lands brought into cultivation through the establishment of irrigation canal from the Nile. The cropping system here is based on green fodder (Egyptian clover in winter and maize in summer), together with wheat in winter and vegetables in summer; crop residues are used for animal feed. The third region is the desert oasis (Siwa) where rainfall is negligible; the communities here depend on ground water and springs as water resource to farm their fragmented lands with alfalfa and strategic crops, plus vegetables and fruits. Animals are raised mainly for household purpose.

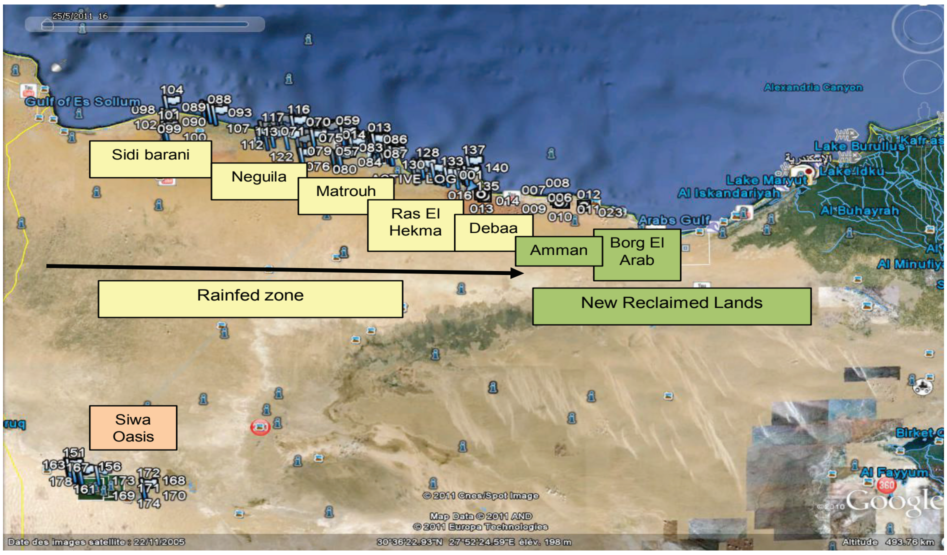


Figure 1: GPS map for the studied area.

As the area had witnessed a long period of drought, from 1995 to 2010, a field survey was carried out to assess the socioeconomic vulnerability of the local communities under the prolonged drought conditions and the role of livestock in sustaining their livelihood in the three different agro-ecological regions of the CZWD.

Materials and methods

The field survey was carried out of 182 livestock breeders, distributed all over CZWD, during April –July 2011 (124 in the rain-fed area, 28 in the newly reclaimed lands, and 30 in the desert oasis). The survey dealt with the activities of the communities related to livestock, agriculture and off-farm income generation in the 3 agro-ecological regions. It also assessed the vulnerability and socioeconomic indicators of households. The questionnaire applied included information on: family structure, housing, and off farm activities; land and cropping system; livestock structure, range status, grazing practices, feeding and management; animal performance and marketing; and constraints and perception of climatic conditions.

Cluster analysis was carried out based on a multiple factor analysis (Escofier and Pages 1994). Firstly, a multiple factor analysis (MFA) was used to obtain the overall relationship between different variables. The second step was to classify farms on the basis of the results obtained from the MFA, calculating a series of scores for each farm that expressed similarities and differences between the farms (Manly 1994). These scores were used to construct a hierarchy of partitions through agglomerative hierarchical classification. All calculations were performed using XLSTAT with Excel.

Results

Development of flock size and structure with the long drought incidence

The field survey showed that flock size had decreased in the rain-fed area over the drought period from 244.1 in 1995 to 151.8 heads in 2011 (-38%,Table 1). Large flocks (>1000 head) had disappeared from the area with the deterioration of the natural ranges. The second observation was the increase of the proportion of goats in the flocks from 20.5 to 22.2%, with a wide range of 4-100% between breeders. Large ruminants raised there are mainly camels with some cattle (4.5 heads in average/household).

Goats dominated in Siwa desert oasis with doe/ewe ratio of 0.68. Other interesting finding was that 20% of the breeders there raise only goats. On the other hand, with the availability of green fodder and crop residuals, flock size had increased in the newly reclaimed land from 160 heads in 1995 to 234 heads in 2011 (+45.6%). Doe to ewe ratio was only 0.14. Each farmer had on average 3.1 heads of large ruminants (cattle).

Family consumption from livestock

The nutritional status of the households in such hot dry area, especially of the vulnerable family members, viz. women and children, depends on the consumption of domestically produced meat and milk from their flocks. A family of 21 members, in the rain-fed area, used on average 14.1 % of their goats and 2.7% of their sheep for meat consumption (Table 2). The family further consumed annually 270 lb of goat milk during the milking season (winter and spring).

Table 1: Development of flock size and structure over the drought period (1995-2011)

Area (number of breeders)		1995				2011				
		Sheep	Goat	Flock size	%Goat	Sheep	Goat	Flock size	%Goat	Large ruminants
Rain-fed (124)	Mean Range	200 12-5000	44.0 4-700	244.1 19-5700	20.5 5-56	127.7 4-4500	24.1 1-320	151.8 6-4820	22.2 4-100	4.5 0-45 camel/cattle
Reclaimed land (28)	Mean Range	142.2 7-600	18.4 5-100	160.6 7-670	14.2 2-100	213.4 16-830	20.5 7-82	233.8 23-856	16.6 3-100	3.10 0-20 cattle
Oasis (30)	Mean Range	30.9 2-300	26.8 2-300	57.7 6-400	32.2 20-100	37.4 3-405	27.4 5-122	64.9 7-527	56.5 20-100	0.2-3 cattle

Table 2: Family consumption of livestock (heads per year) and their products (milk) in 2011

Region	Small holders		Medium holders		Large holders		Average		
	SR Head/yr	Milk Lb./yr	SR Head/yr	Milk Lb./yr	SR Head/yr	Milk Lb./yr	Family members	SR Head/yr	Milk Lb./yr
Rain-fed	2.9	199	5.2	501	15.7	450	20.9	4.1	270
Reclaimed land	3.6	403	5.0	698	4.0	210	20.7	4.0	448

Oasis	2.4	251	8.6	327	19.5	375	15.7	5.8	287

In the oasis, goats are the main source of meat for the family. A family of 16 members consumed 4.1 heads on average annually (15% of their herd) compared to 1.7 heads of sheep (4.5% of the flock). On the other hand, sheep was the main source of meat in the newly reclaimed land. A family consumed on average 3.6 heads of sheep annually, together with 0.7 head of goats. Furthermore, the family consumed annually 448 lb of goat milk, even with the presence of dairy cattle.

Livestock contribution to household income per region

Contribution of livestock to cash income of households came largely from marketing live animals, mainly sheep and goats, at different stages of production: at weaning after early fattening of 1-2 months, after late fattening for 4 to 6 months, and mature animals with or without their kids.

With the poor ranges and lack of feed resources in the rain fed area, > 90% of the livestock breeders sold their kids and lambs at weaning or a few weeks later. Some practiced late fattening of their lambs and kids (9 and 3%, respectively). More than 50% of the cash income in the rain-fed area came from selling weaned lambs and kids, and 24% from early fattened ones. Late fattening contributed only 12% of their cash, and 15% came from selling mature ewes and does (Table 3).

Table 3: Percentage of cash income from different marketing strategies of live animals in the three agro- ecological regions

Regions	**weaned lambs and kids (% of breeders)**	**early fattened lambs and kids (% of breeders)**	**late fattened lambs and kids (% of breeders)**	**mature ewes and dams (% of breeders)**	**large ruminants (% of breeders)**
Rain-fed	50.2 (53)	23.4 (38)	11.6 (9)	14.8 (78)	1.0 (10)
Reclaimed land	15.1 (40)	28.9 (28)	42.6 (32)	13.4 (96)	4.0 (19)
Oasis	29.5 (30)	62.0 (58)	0.60 (12)	7.9 (33)	1.0 (3)

Similarly, most of the breeders in desert Siwa oasis sold their kids and lambs at weaning stage or a few weeks later .Only 12% breeders practiced lamb fattening and there was no kid fattening. Sixty two percentage of their cash income came from selling early fattened lambs and kids and 30% from selling the weaned ones

Marketing strategy in the newly reclaimed lands differed; 40 and 65% of the breeders sold their lambs and kids, respectively, after weaning, 28 and 10% after short fattening, and 32 and 25% after late fattening. More than 43% of their income came from selling late fattened lambs and kids, 29% from early fattening, and only 15% come from selling weaned lambs and kids.

Most of the breeders in the three regions sold part of their mature ewes around the year as a source of cash to buy feed stuffs for the rest of the flock. They used ewes as their cash asset.

Livestock contribution to household income as per farm type

Table 4 presents the contribution of livestock to the net income of the local community for each farm type in the three agro-ecological regions. Livestock contribution to the net income of the local community in the rain-fed region differed significantly with the flock size, ranging from 28

Table 4: Contribution of livestock to the livelihood of the community in the 3 agro ecological regions

Parameters	**Small holder**	**Medium holder**	**Large holder**	**Average**
A . Rain-fed				
No. households	89	22	7	118
(Rain-fed areas (acre	15.1	52.2	65.9	25.0
(Wadi area(acre	5.7	16.3	16.7	8.3
(Rangeland (acre	7.7	84.9	162.9	31.3
(Feed costs in 2011 (1000EGP	36	63	273	55
(Annual net income per family(1000 EGP	27	149	121	55
(%)Net income from livestock / annual income	28	44	80	43
(%) Net income from SR/annual income	95	99	84	90
(%) Net income from off farm activities/annual income	34	14	9	21
(%) Net income from crop activities/ annual income	38	42	11	36
B. New reclaimed land				
No of householders	18	8	5	31
(Rain fed area (acre	2.4	0.8	0.0	1.6
(Irrigated area (acre	2.2	23.4	36.6	13.2
(Total feed cost (1000 EGP	22	48	304	74
(Average annual net income per family(1000 EGP	34	201	419	139
(%) Net income from Livestock/ total annual income	58	54	71	62
(%) Net income from SR/livestock income	55	53	60	56
(%) Net income from off farm activities/ total income	22	10	1	8
(%) Net income from crop activities/ total income	21	36	28	30
C . Desert oasis				
No. Of householders	17	11	2	30
(Wadi area (valley ,acre	0.8	5.4	18.0	3.7
(Irrigated area (acre	0.8	2.0	0.0	1.2
(Feed cost in 2011 (1000EGP	12	11	0.4	11
(Annual net income per family(1000GPE	16	69	342	57
(%) Net income from Livestock/ annual net income	6	20	46	28
(%) Net income from SR/total livestock income	76	91	87	85
(%)Net income from off farm activities/annual income	38	36	1	23
(%) Net income from crop activities/ annual income	56	44	53	49

% for the small flocks to 44 % for the medium size one, and up to 80 % for the large flock owners, mainly from sheep and goats. Livestock contribution in the newly reclaimed lands was related to farm size; ranging from 58 % for small farms (< 2 acres) to 71% for large farms (>35 acres). Share of small ruminants on the total livestock income was 95 % for the small farms and 84% for the large farmers. Source of income in the desert oasis was highly diversified and livestock contribution ranged from 6% for small holders to 46% for large holders.

Multi-factor analysis of livestock contribution to livelihood in the three regions

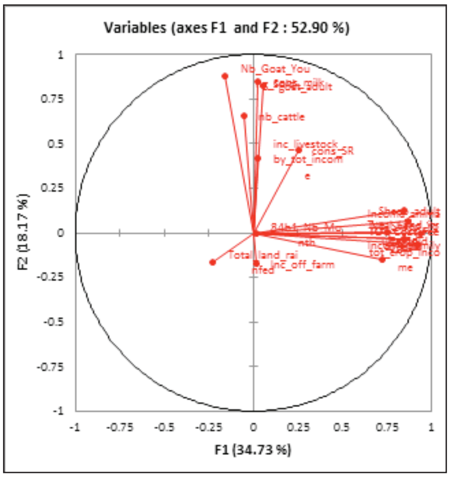
Figure 2 shows the results of the multi-factor analysis of the main factors determining livestock contribution to the livelihood of the local community in the three agro ecological regions. In the rain-fed zone, the main factor (F1) explains 52.6% of variability between the farmers. This factor is explained by the structural variables like land area in the rain-fed (barley) and Wadi zones (valley) and the flock size, mainly number of sheep heads. So we can differentiate the small and large holders. The small holder in this area has less than 15 acres under barley zone and 5-6 acres in the Wadi zone, with a flock size of around 50 animals, compared to the large ones with 66 acres in barley zone and 16.7 acres in the Wadi zone and a flock size around 226 heads. The second factor allows to differentiate a third group, the medium holders who are close to the large farm in terms of access to land, but have a smaller flock of 100-120 heads and with no agricultural activity.

In the desert oasis, the three first factors represent 65% of all the variability in the population. The first and main factor (F1) of differentiation is based on the livestock contribution to the farming system, and goat herd size. So we have the large holders with more than 200 heads of small ruminants. The second factor differentiates the population according to the feed supply (from farm or market), followed by the feed cost per animal. The last factor differentiates the population according to crop income and land use, but not land size. This situation is specific to Siwa oasis, where the attribution of the cultivated land is quite homogeneous among farmers. The two last factors allow differentiating the medium and small holders according to access to Wadi and irrigated lands; 5.4 and 2 acres for medium holders, and < 1 acre from both types of land for small holders.

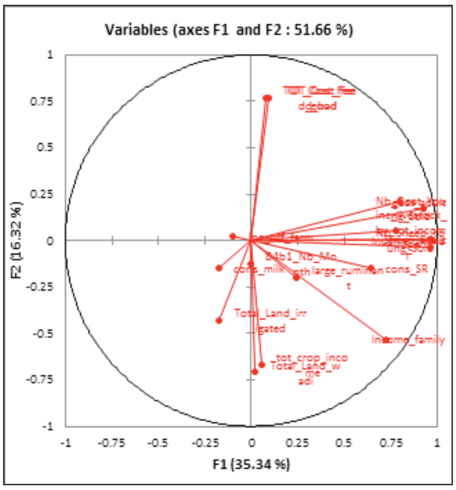
In the newly reclaimed land, two main factors represent 52.8% of the variability. The first factor (F1) differentiates the population according to the main physical assets as irrigated land and sheep flock size. This factor allows to separate two groups: the small farms with 2-3 acres in irrigated land and < 100 sheep and goat, compared to large farmers with > 30 acres in irrigated lands and a flock size around 300-400 heads. On the second axis the third type named the medium holder can be differentiated. This group has the largest goat flock with around 17 heads and 2-3 dairy cattle.

Discussion and conclusions

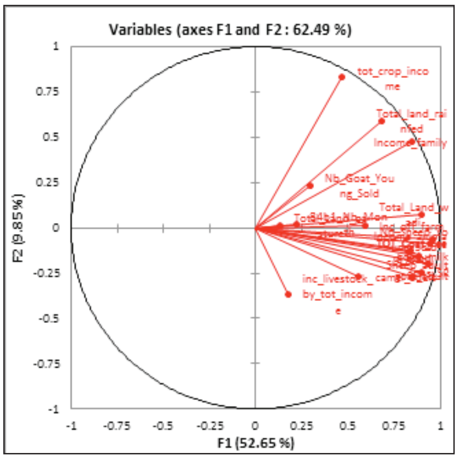
The study analyzed the contribution of livestock to the livelihood of the local community in the hot dry area of Coastal Zone of Western Desert of Egypt, and the impact of the long drought (1995 – 2011on the livestock farming system in its three agro-ecological regions: rain-fed, reclaimed land and desert oasis. Decreasing flock size was the major adaptive process taken by the Bedouin in the rain-fed area to cope with the incidence of the long drought and the deterioration of range conditions. Raising goats was the other means of adaptation to drought. The explanation given by the breeders in this regard was that goats gave them more flexibility in coping with climatic change, including the incidence of recurring drought, than other animals (Alary *et al.* 2011). Raising goat as more adapted livestock to predominantly arid and semi arid conditions and as a potential way to cope with harsh drought conditions had been reported by many authors (Bhatacharya 1980; Davendra 2012). With the availability of green fodder and crop residues, the



Newly reclaimed land



Desert Oasis



Rain –fed area

Figure 2: Multi factorial analysis of contribution of livestock to livelihood of local community.

reverse was the case in the newly reclaimed land, where the communities increased their flock size over the same period, mainly sheep.

An interesting advantage of raising goats in the rain-fed area was the higher income from goats over sheep, than in the reclaimed land and the oasis (66% vs., 56 and 57%, respectively). Goats are skillful grazing animals and have efficient digestive system, utilizing poor roughage as reported by Silenikove (2000), and this was recognizable in the rain-fed area with the long drought incidence, and partly in the desert oasis, but not in the new reclaimed lands. Goats contributed significantly to the nutritional status of the householders in the whole area, through both meat and milk in the rain-fed and oasis areas, and through milk in the newly reclaimed lands.

Livestock contribution to the income of the local community in the rain-fed region differed significantly with flock size. In the new reclaimed lands, livestock contribution was mainly related to farm size. Source of income in the desert Siwa oasis was highly diversified, livestock contribution ranged from 6% for small holders to 46% for large holders. Mature does and ewes served as cash assets for the breeders around the year in the three regions. The breeders in the rain-fed region tend to maintain their productive does in the drought years for restocking their flocks after the drought period (Osman *et al.* 2012).

The results confirmed the key role of small ruminants in the hot dry areas, especially when facing the harsh climatic conditions, as reported by many authors (Salinkove 2000; Alary *et al.* 2012). They are a reliable means to improve the livelihood of local communities there. Share of small ruminants in the income from livestock was 90 % in the rain-fed area and 56 % in the newly reclaimed lands.

Off–farm activities contributed moderately to the income of the small holders in the three regions, and they are essential to cover the basic needs of the families. Crops (mainly cereals) and fruit trees contributed significantly to the income of oasis communities, and moderately to the small and medium size breeders in the rain-fed area and the reclaimed land.

Scooned (2009) reported that the consideration of all socioeconomic factors is the only way to explain the factors that contribute to the livelihood of the householders. The multi-factor analysis of the present data indicated that the main factors that contributed to the variability in the role of livestock in the livelihood of the local community were the structural variables (land types) in the rain fed area, the physical assets (irrigated lands and sheep flocks) in the new reclaimed land, and the farming system (and goat herds) in the desert oasis.

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Sustainable resource management in dry land Arabia

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Abstract

The Arabian Peninsula is classified as one of the most hyper arid regions in the world. The peninsula has huge land area, surrounded by salty water. It faces serious issues of limited fertile land and water scarcity. Although rich in oil and gas resources, the region's water and food resources are insecure; the region imports over 70% of its food requirement. The sustainable resource management is widely used in rural development globally, but has been under-used in dryland regions. It is a framework of thinking and short listing factors that impact various stakeholders and natural resource condition. Currently, there is a low level of public awareness about the challenges that are faced by the region to achieve sustainable resource management. There has been, however, some political and social attention given to sustainable resource management championed by the Global Dry Land Alliance (GDLA). The region's resource constraints should be addressed and community-based natural management should be the basis of any human-nature nexus evaluation. Collective approach is needed to achieve sustainable results. This paper aims to contribute to improved understanding of the dynamics of regional socio-ecological systems.

Introduction

Among the world's major ecosystems, those of the drylands have received the least attention, disproportionate to their size, population, and importance for global sustainability. They are inadequately understood by the world's policy makers and even by those of dryland countries. Drylands cover approximately forty per cent of the earth's land surface and provide a means of livelihood for about one billion people, mainly in developing countries. Drylands are defined by water scarcity and characterized by seasonal climatic extremes and unpredictable rainfall patterns. Temperature extremes are very common. Tropical drylands may have very hot summers and temperate ones, very cold winters. Most soils in drylands have low fertility together with moisture limitations; hence their capacity to support woodland, grassland or crops is quite limited (Mortimore *et al.* 2008).

The Arabian Peninsula is classified as a hyper-arid region as shown in Figure 1. The climate of the Arabian Peninsula is widely considered as one of the driest on record (Kotwicki and Al Sulaimani 2009). The Arabian Peninsula has been undergoing a process of steady desiccation, a drying up of rivers and a spread of the desert at the expense of the cultivable land. The declining productivity, together with the increase in the number of the inhabitants, has led to a series of crises of overpopulation and consequently to a recurring cycle of depopulation of the Peninsula, when people migrated in search of more rain (Homiedan 2008).

At present, the Arabian Peninsular region is 99 percent arid and hyper arid (HA) as per UNESCO (1997) classification as follows (Table 1). In addition to the fact that the region has the lowest rainfall on the planet, rainfall distribution is unfavorable, falling in sudden and erratic showers, with high intra-annual variability. More than 90 percent of the Arabian Peninsula has a mean annual temperature of 20°C, with smaller area experiencing annual temperature exceeding 30°C.

Table 1: Moisture regimes of the Arabian Peninsula (Kotwicki and Al Sulaimani 2009)

Moisture regime	**Aridity index**	**of total area %**	**km²**
Hyper-arid	0.03>	32.02	1,020,107
Arid	0.03-0.2	66.72	225,415
Semi-arid	0.2-0.5	1.22	38,788
Sub-Humid	0.5<	0.04	1.199

It is forecasted that over the next decade, the region's population will increase by 30% to over 50 million people. The Arabic Gulf region will therefore see an increasing strain on its supplies of electricity, food and water. The ways in which the region faces up to these challenges will have a major impact on its prosperity and quality of life, in the decades to come.

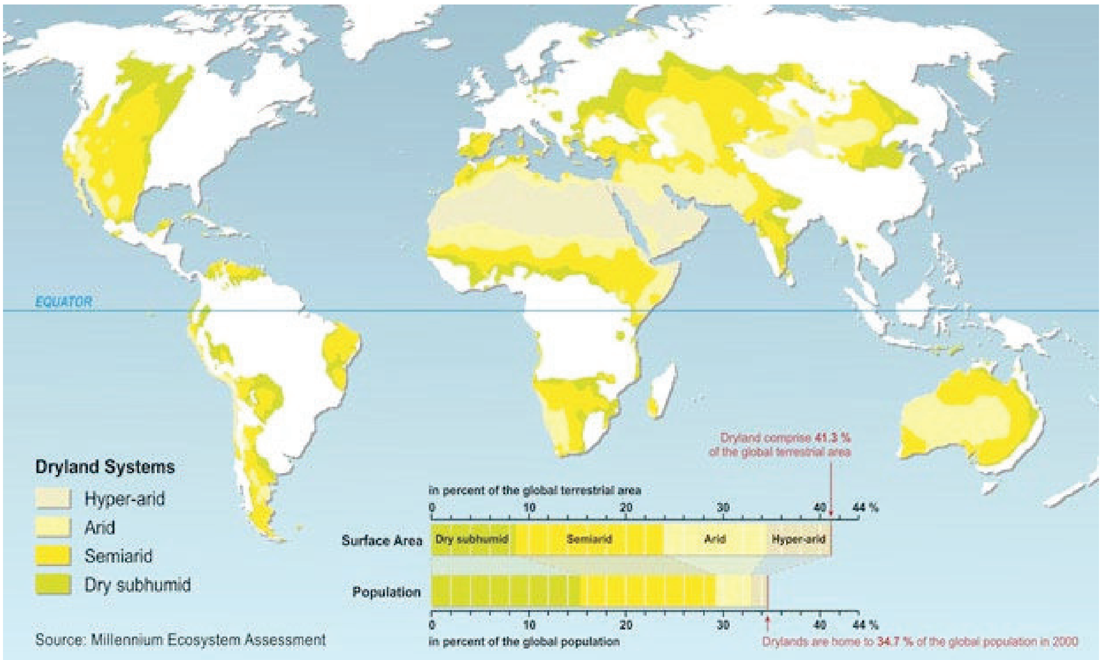

Figure 1: Distribution of the World's drylands according to aridity zones (based on UNEP 1992).

The pursuit of sustainability

The pursuit of sustainability in resource management refers to ensuring a high reliability of meeting future demands without compromising on the water-food-energy nexus integrity. Dryland Arabia has limited groundwater resources, and has growing signs that its groundwater is being depleted by overuse. The region is thus facing a potential water shortage. Meeting the rising water demand due to the overwhelming increase in population that adopts an increasingly water-intensive lifestyle and economic development activities puts the region's fortune at stake. The region will have to rely increasingly on desalinated water, which is expensive and energy intensive. At present, there are considerable inefficiencies all along the production, distribution and consumption chain, starting with energy-inefficient production and ending with inefficient water consumption. Large scale water resource systems inherently possess a number of uncertainties, including those due to climate change and conflicting goals of various stakeholders. Recently developed modeling techniques would be useful to develop policies for sustainable management of water resources systems (Mujumdar 2008).

In order to ensure that the pursuit of sustainability is feasible, it is paramount to consider all levels of the problem and address all stakeholders involved. Economic growth *per se* carries lots of implications for sustainability. Thus it is essential to dovetail beneficial growth now with safeguarding the future sustainability. The positioning of this balance must be determined by the governmental bodies assisted by public interventions.

Relevant research has shown economic potential in similar arid land. Abu Rabia *et al.* (2008) investigated Bedouin dryland in the northern Negev. The farm that was investigated consists of about 120 ha of semi-desert land 30 km east of Beer Sheva. The area receives an average rainfall of 200 mm per year. The analysis demonstrated the potential of dryland agroforestry for sustainable development while solving a number of economic and social problems of poor dryland inhabitants. The study demonstrated that sustainable dryland exploitation by agro-forestry can establish significant agricultural production potential on marginal lands often considered worthless. Similar case-study was done in southern Greece by Petropoulou (2007), who investigated the potential of natural resource management practices of diversified system in a mountainous farming community. The research indicated that mountain farming communities need to be educated on the anthropological aspects of resource degradation and the interrelatedness of cultural activities and the physical world.

'Water-Food-Energy' nexus

Water, energy, and food security are intimately linked and thus integrated as shown in Figure 2. In simple terms, food production demands water; water extraction, treatment, and redistribution demand energy; and energy production requires water. Energy inputs via fertilizers, tillage, irrigation, harvesting, and transport and processing of produce have their influence on food prices. Food production practices have great influence on water and clean water harvesting. The problem of the water shortage is connected mainly to the rise of the living standards, to the urbanization, to the irrational water use in the agricultural and industrial activities, as well as to the lack of proper environmental policy (Mariolakos 2006). The need for a nexus approach across sectors and scale is paramount to achieve a sustainable solution. The inter-relatedness between the three main components in the nexus makes it unsustainable to single-out one element and put at risk renewable long term resource use. A nexus approach is needed to support the transition to sustainable resource management. It aims, among other things, at resource use efficiency and greater policy coherence.

An example of a promising story is that of the Masdar City in UAE. This new master-planned city in the United Arab Emirates aims to produce no waste and to be carbon neutral, relying on different types of green technologies. It will be entirely supplied by renewable energy generated by ground based and roof-mounted photovoltaics, which are connected through a smart grid; concentrating solar power; evacuated tube collectors; and geothermal heat pumps. In response to the extreme water scarcity in the region, Masdar City is designed to reduce the domestic

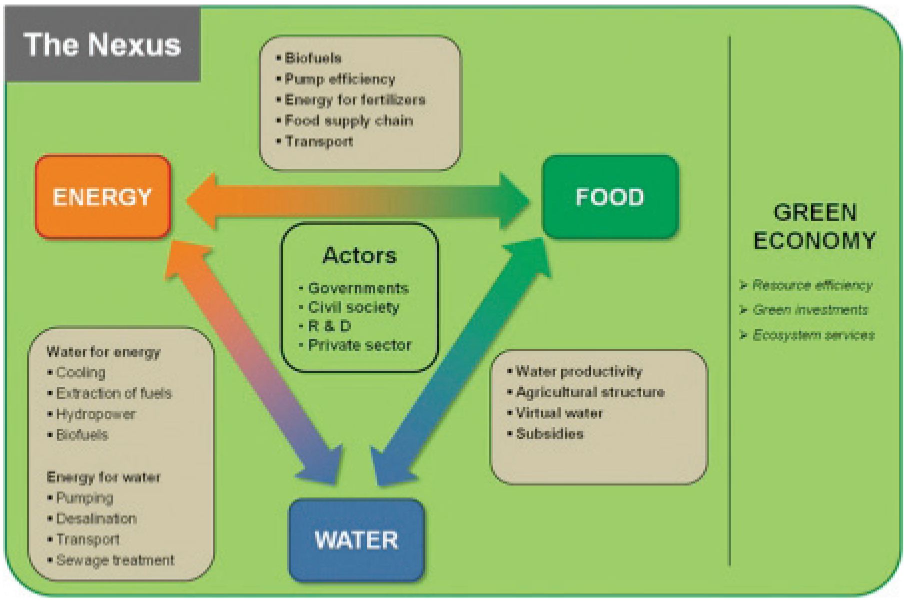

Figure 2: Water-food-energy nexus (Source: Secretariat of the Bonn 2011 Nexus Conference)

consumption of water to a maximum of 100 litres per person per day through use of low-flow showers, highly efficient laundry systems, water tariffs, real-time monitoring, and smart water meters. It also aims to reuse 100% of processed wastewater for irrigation.

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Effects of dust events on daily outpatient counts

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Abstract

Dust events are common air pollution events in parts of the world with arid, semi-arid, or desert areas. There are few researches on the acute effects of dust events. The aim of this study was to assess the association between daily outpatient counts and dust events. The study was done using daily outpatient counts of each clinical department in Z Hospital in Loess Plateau where dust events are the most frequent in China. The survey period was between 1 April, 2012 and 30 June, 2012. The dust events were judged by Air Pollution Index (API), and API are announced in the local environmental monitoring center. Temperature, and the relative humidity was used at the same time as confounding variables. The information, released at the meteorological center, was obtained from the website. The results suggest that the increase of outpatient counts by the dust events was not found, but the increase of the outpatient numbers to the pediatrics cannot be denied. In addition, it was revealed that the influence of weather factors such as temperature or the humidity was bigger than the dust particle.

Introduction

Dust storm events occur in China in winter and spring (November to May), especially between March and May, and mainly originate in the Gobi and TaklaMakan deserts in Mongolia and western China. Particulate matter (PM) levels in dust events, especially particulate matter with aerodynamic diameters less than 10 μm (PM_{10}), have been recorded above 500 μg/m^3, and sometimes over 1000 μg/m^3, during several dust events in many downwind area cities (Kim *et al.* 2010; Song *et al.* 2006). A dust event in East Asia on 21-23 March, 2010 caused several Asian cities to experience the worst air quality recorded in recent years. The Shanghai Environmental Protection Bureau recorded a 24-hour average air pollution index (API) of above 500 on 21 March (Shanghai Environmental Protection Bureau 2010); and the Environmental Protection Department of Hong Kong recorded peak hourly API above 500 on 22-23 March (Hong Kong Environmental Protection Department 2010).

The impact of dust events on health has become a major concern in recent years. Both animal and human studies have investigated potential adverse effects corresponding to the PM pollution in a dust event. Studies on experimental rats have demonstrated the significant toxicological effects of PM on inflammation, heart rate, and blood pressure during dust events (Chang *et al.* 2005, 2007; Lei *et al.* 2004). Epidemiological studies have also shown that dust events increased emergency room visits or daily hospital admissions for ischemic heart diseases, cerebrovascular diseases, and chronic obstructive pulmonary diseases (Chan *et al.* 2008). However, the effect of dust events on outpatients is still unclear. The main purpose of this study was to assess the association between daily outpatient counts and dust events.

Methods

The daily outpatient counts of each clinical department were obtained from Z Hospital in Loess Plateau where dust events are the most frequent in all of China. The survey period was between 1 April, 2012 and 30 June, 2012. Meteorological information (temperature and the relative humidity) was used at the same time as confounding variables, and was released at the meteorological center and obtained from the website.

Dust events were judged by the air pollution index (API), and the API was announced in the local environmental monitoring center. In total, 6 dust event days were identified in the survey period.

For statistical analysis, we compared outpatient counts on non–dust days with dust days during the same period using the Student's t test. Pearson's product moment correlation coefficient was used to determine the correlation between outpatient counts and API. All data analyses were performed using SPSS for Windows (SPSS), and a significance level of 5% was used.

Results and discussion

Table 1 shows the average values of API levels and measurements for dust days and non-dust days. The average API level for dust days was significantly higher (P=0.004) than that for non-dust days, and the average temperature for non-dust days was significantly higher (P=0.014) than that for dust days. There was no significant difference in relative humidity between dust days and non-dust days.

Table 1: Average values of API, temperature, and relative humidity on dust days and non-dust days

Variable	Non dust days (n=57)	Dust days (n=6)	*P*-value
Air Pollution Index (API)	49.74±18.40	140.17±44.61	0.004
Temperature	15.17±3.96	10.79±4.67	0.014
Relative humidity	42.39±19.74	30.15±11.88	0.056

Figure 1 shows the distribution of outpatient counts in each clinical department between dust days and non-dust days. The outpatient count for pediatrics on dust days (16.50±5.65) was significantly higher than that on non-dust days (12.57±3.78, $P<0.05$). The outpatient count for pediatrics was positively correlated with API levels ($R=0.390$, $P=0.001$; Fig. 2).

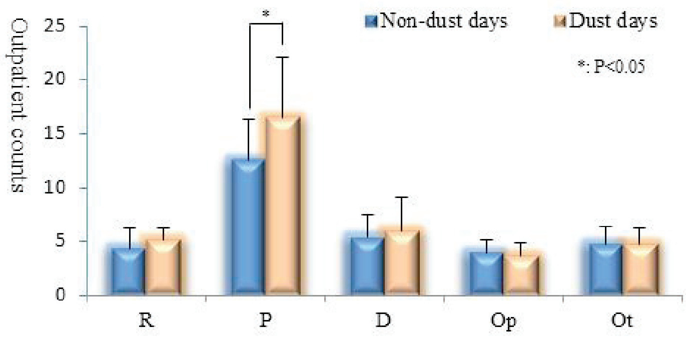

Figure 1: Comparison of the outpatient counts in each clinical department between dust days and non-dust days. R, Respiratory medicine; P, Pediatrics; D, Dermatology; Op, Ophthalmology; Ot, Otorhinolaryngology.

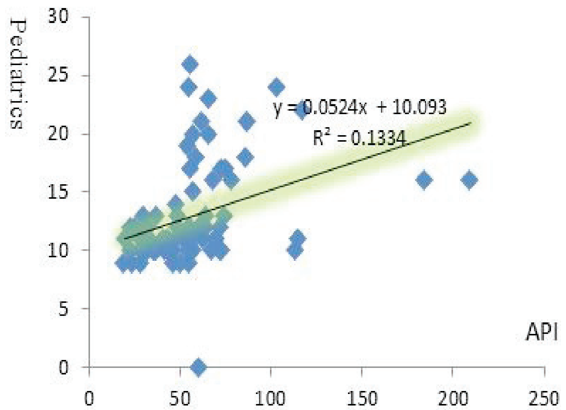

Figure 2: Correlation between the outpatient count for pediatrics and API levels.

This study was designed to assess the acute effect of dust events on daily outpatient counts in Loess Plateau. Until now, many studies have investigated the aggravation of symptoms in the elderly and patients with chronic disease (Chan and Ng 2011; Meng and Lu 2007). The results of this study have shown, for the first time, the acute effect of dust events on the outpatient count for pediatrics. A correlation between the outpatient count for pediatrics and dust events can be explained by significantly increased mass concentrations and changing components in PM during the dust storm, the growth period of and reduced immunity in children, and the longer exposure time of children to the dust. In addition, weather conditions were not adjusted for; therefore, they may be an alternative cause of the effects found in this study.

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Panel Discussion

Panel Discussion

Rio+20, the way forward – Role of government, non-governmental organizations and private sector

Panel co-chairs: Dr Zafar Adeel & Dr Adel El-Beltagy
Keynote: Ambassador Zu-kang Sha, Secretary General of Rio+20 Summit, Former UN Under-Secretary General
Panel members: Drs Gareth Wyn Jones, William Payne, Tao Wang

Introductory remarks by Panel Co-chair Dr Adel El-Beltagy

The Panel co-chair welcomed the keynote speaker Ambassador Zu-kang Sha, members of the Panel, and the Conference participants to the panel discussion.

Giving a brief overview of Rio+20, the United Nations Conference on Sustainable Development, Dr El-Beltagy said the Conference brought together Governments, corporations, investors and lay persons to deliberate on how the world could be put on a more sustainable course in environmental, economic, social and governance spheres. The Conference, held in June 2012, fostered "a stronger sense of shared purpose and collective responsibility to move from the status quo toward a more sustainable future". A notable feature of Rio+20 was the agreement of Governments to define a new set of Sustainable Development Goals (SDGs) that would broaden progress already made in the context of Millennium Development Goals.

Prior to the Conference, a Corporate Sustainability Forum was organized by the UN Global Compact "to provide a launching pad for greater private sector and investor involvement in sustainable development and to call the Governments to take steps that will support corporate sustainability goals". The Forum saw the launch of more than 200 different initiatives by companies covering energy, climate change, water, food, women's empowerment etc., several of which had potential of setting new paradigms, e.g., "frameworks for public-private policy collaboration on biodiversity, on food and agriculture, and on access to water for people and industry".

Technological innovations with respect to Energy and Climate pertained to reducing the cost of renewable energy technology, improve access to energy sources and help enhance resilience to climate change. Examples discussed included (a) developing better renewable energy technologies (e.g. organic photovoltaic solar panels for use in unique places; more efficient wind turbines using reduced- weight aerodynamic fibers; improved energy storage supporting the large-scale use of wind and solar power); (b) developing and improving other alternative energy sources (e.g. scientific breakthroughs leading to the creation of next generation biofuels with less impact on food supply); and (c) developing enabling technologies (e.g. mobile phone applications and other technologies that could help build farmers resilience to climate changes and help NGOs to efficiently collect and analyze data to support building community resilience; applications that help improving the accuracy and timeliness of climate-related information analysis and decision making). Policy recommendation to the Governments was to end all subsidies to fossil fuels and reorient subsidies towards clean and renewable energy.

Technological innovations with respect to Corporate Water Sustainability and Ecosystems Management included (a) developing new or enhanced technologies for water efficiency and waste-water management (e.g. advanced recycling systems at factories; on-site waste-water treatment facilities; and, in agriculture, new-generation drip-irrigation systems and new water-efficient crops); (b) developing sophisticated water foot-printing methodologies to permit better understanding of the full extent of their direct and indirect water use, creating opportunities to offer water-sensitive products (e.g. crops and other commodities grown with less water).

With respect to Food and Agriculture, it was recognized that companies involved in this sector have an important role to play in sustainability with respect to food, nutrition, and agriculture. The new global challenges require that the private sector implement sustainable agricultural practices that treat each actor along the supply chain equitably, protect and enhance environment, meet the needs of future generations, contribute to an improvement in food security and access, and help in reduction of poverty. Accordingly, the leaders in sustainable agriculture are adopting several innovative approaches including (a) sustainable and inclusive sourcing of products, especially from small holder farmers, to reduce poverty by empowering farmers and linking them to markets; (b) investing in innovative new water management systems that enhance water use efficiency and productivity; (c) promoting climate- smart agricultural practices, including crop rotations, reduced use of chemical fertilizers, and prohibiting expansion of agriculture in protected areas to prevent land degradation; (d) developing innovative methods to enhance the nutritive value of crops while still on ground and nutritionally fortify food during processing; and (e) providing new technology to farmers to access weather and market information, reduce storage losses, reduce crop risks, and enhance drought tolerance of their crops.

Concluding his comments Dr El-Beltagy said that the emphasis in Rio+20 for sustainable development has great importance for the dry areas of the developing world where the resources of land, water and biodiversity are threatened resources in the face of global climate change, as will be further revealed by the presentations to be made by the panel members and discussions that would follow. He then invited panelist Dr Gareth Wyn-Jones to present his views.

Dr Gareth Wyn-Jones appreciated the initiative by the corporations to move towards green economy and their commitment to help agricultural sector to contribute to the sustainable development agenda. The scientific innovations with respect to production of renewable energy that does not impinge on food production, more efficient irrigation and water use, and development of climate-smart crops and varieties would help reduce the greenhouse gas emission foot print of agriculture. Dr El-Beltagy thanked Dr Gareth Wyn-Jones for his observations and the invited Ambassador Zu-kang Sha to deliver his keynote address.

Keynote address by Ambassador Zu-kang Sha

Ladies and Gentlemen, it is a great pleasure for me to join you at this International Conference on Dryland Development. Back in early 2008, when I was the United Nations Under-Secretary-General, heading the Department of Economic and Social Affairs, the first international conference the Department co-organized with the Chinese Government during my term, was on desertification and dryland issues. We convened that conference together with the State Forestry Administration of China and the secretariat of the UN Convention to Combat Desertification. The

Conference aimed to address linkages among desertification, hunger and poverty and sustainable agriculture and rural development in dryland areas. The broad range of issues examined at the 2008 Conference was very close to the agenda of this International Conference. But the focus then was on indentifying barriers and constraints, and on exchanging lessons learned and best practices, in combating desertification. I am sure this gathering, with so many distinguished experts leading the discussions, will provide a multi-disciplinary platform for identifying balanced and integrated solutions. So, I want to start by congratulating the organizers for developing a rich and yet inter-connected programme on the social, economic and environmental challenges facing dryland communities.

In my remarks today, I want to share with you the UN perspectives on desertification and dryland development challenges. I will also brief you on the Rio+ outcome and the current follow-up to Rio+20, including the discussion on Sustainable Development Goals (SDGs).

I had the opportunity to guide the preparations for the Rio+20 Conference and its follow-up processes as the Conference Secretary-General. According to the United Nations Convention to Combat Desertification (UNCCD), worldwide, some 70 percent of the 5.2 billion hectares of agricultural land in arid areas are degraded and threatened by desertification.Every year, 12 million hectares of land become unproductive through desertification and drought. Every year, 75 billion tons of soil are lost forever.Globally, 1.5 billion people are directly affected by land degradation. Approximately, 135 million people are at risk of displacement as a consequence of desertification, with broad long-term social-economic implications.

Climate change is exacerbating the extent and impact of desertification through reduced water availability, increased frequency of droughts and increased changes in rainfall. With the degradation of natural resources continuing, the investments in agriculture and rural development in these areas tend to decline, further deepening rural poverty and impeding sustainable development. Combating desertification and developing dryland economy is therefore a fundamental sustainable development challenge – at stake are both the dryland ecosystems and the sustainable livelihoods of millions of peoples who call dryland home.

Indeed, the United Nations has sought to meet this challenge through a legal instrument – the UN Convention to Combat Desertification – and through mobilizing political will for action. Deserts and dryland are among the "fragile ecosystems" addressed by Agenda 21 during the Rio Conference in 1992. In 1994, the United Nations General Assembly declared June 17 the "World Day to Combat Desertification and Drought" to promote public awareness of the issue, and the implementation of the UN Convention to Combat Desertification. The World Day to Combat Desertification has become a unique occasion to remind everybody that desertification can be effectively tackled, that solutions are possible, and that key tools to this aim lay in strengthened community participation and co-operation at all levels.

The United Nations General Assembly also declared the year 2006 the International Year of Deserts and Desertification, to raise global public awareness of the land degradation, of ways to safeguard the biological diversity of arid lands and protecting the livelihoods of millions of people affected by desertification. Combating desertification and drought had also been reviewed by the UN Commission on Sustainable Development, including during its 2008-2009 cycle.

In the lead-up to the Rio+20 Conference, drought, land degradation, desertification and dryland are among the critical challenges highlighted by Governments, business and civil society, including research and academic communities. In over 150 submissions to the outcome document, governments and other stakeholders called for action to address the inter-linked challenges facing the vulnerable communities in dryland regions. In September 2011, the UN General Assembly held a high-level meeting on the theme: “Addressing desertification, land degradation and drought in the context of sustainable development and poverty eradication”. In preparation for Rio+20, many countries called for a land degradation neutral world, with a sustainable development target of “zero-net land degradation”. The Zero Net Land Degradation target advocates that sustainable land-use is a prerequisite for ensuring future water, food and energy security. Given the increasing pressure on land from agriculture, forestry, pasture, energy production and urbanization, urgent actions is needed to halt land degradation. The calls for actions to slow, halt, and reverse land degradation and desertification resonated with world leaders.

In the Rio+20 outcome, Members States recognized the economic and social significance of good land management, particularly its contribution to economic growth, poverty eradication, biodiversity, sustainable agriculture and food security, addressing climate change and improving water availability. They recognized the need for urgent actions to reverse land degradation, to achieve a land-degradation neutral world in the context of sustainable development. Members States further reaffirmed their resolve to take coordinated action to monitor, globally, land degradation and restore degraded lands in arid, semi-arid and dry sub-humid areas. They encouraged capacity-building and scientific and technological initiatives, aimed at deepening understanding and raising awareness of the economic, social and environmental benefits of sustainable land management. They stressed the importance of the further development and implementation of scientifically based, sound and socially inclusive methods and indicators for monitoring and assessing the extent of desertification, land degradation and drought. They underscored the importance of efforts to promote scientific research and strengthen the scientific base of activities to address desertification and drought. I hope this strong emphasis on the role of science will not be lost on the expert participants in this Conference.

Rio+20 was the largest conference ever convened by the United Nations, attended by more than 100 Heads of State and Government and an estimated 50 000-plus participants, including thousands of representatives from the scientific and academic communities. The outcome document, The Future We Want, reaffirmed Member States’ political commitment to sustainable development. Equally important, Rio+20 launched a historic process to establish universal Sustainable Development Goals (SDGs). A 30-member intergovernmental Open Working Group has been established under the UN General Assembly. Last week, the Open Working Group held its first official meeting in New York at UN Headquarters. There was a strong sense of historic commitment at the meeting, as the SDGs will become the framework for guiding global development in the coming decades.

Rio+20 also recognized that green economy can be an important tool in poverty eradication, and achieving sustainable development.Efforts are under way to prepare toolboxes that can help advance a green economy, and methodologies for evaluation.

I invite the experts at this Conference to look into ways of integrating sustainable land management and sustainable livelihoods in dryland regions into the green economy.

Ladies and gentlemen, before I conclude, I would like to share a few questions for your consideration. I know from the Rio+20 Conference that these relate to the priority areas for policy makers in developing dryland economies. I strongly hope that in your recommendations you will address the following five questions: 1. How to strengthen prevention and mitigation of land degradation; 2. What incentives and measures we should adopt to improve access to land and encourage sustainable land management; 3. How to integrate action in critical sectors and issues for dryland communities, such as biodiversity, food security, water management, energy, including renewable energy, technology innovations, rural-urban migration, climate change and adaptation and mitigation; 4. How to foster international cooperation, including that for capacity-building, information-sharing, and technology transfer; and 5. In addition to zero net land degradation, in your views, what other targets should be included in the sustainable development goals.

*Ladies and gentlemen, w*hile I look forward to your deliberations and recommendations, let me now conclude with a personal note. During the process of preparation of Rio+20 Conference, several "make it or break it" issues were raised. The definition of "green economy" was much discussed as also ways and means to promote "green economy" in light of the fact that not all countries have the necessary "financing, technology and capacity". With the introduction of the concept of "reporting and monitoring" of the progress in developing the "green economy", the question of "criteria for measurement" was raised which generated heated debate. Serious concerns were voiced by developing countries for fear that the use of "criteria and indicators" could be used as justification for trade protection and aid conditionalities. Needless to say, with joint efforts and good will of all parties, consensus was reached on how to address them. All parties agreed that science and technology innovations are key to developing green economy worldwide, particularly for the developing countries. Seeing so many eminent experts present today in this distinguished gathering, I venture to flag the idea, , whether it is possible or feasible for experts and scientists like you to meet more often and work more coherently to come up with practical recommendations for policy decisions makers, and some operational set up for best practices and experience sharing in order to better combat land degradation, particularly the desertification.

*Ladies and gentlemen, l*et me wish you a successful deliberations and a happy stay in China.

Discussion

Dr El-Beltagy thanked the Ambassador for his very enlightening address and so succinctly coming out with issues emerging from Rio+20 that are so relevant for the sustainable development of the dry areas and combating land and water degradation and desertification. There have been so many well-meaning global conventions that have made call for collective action to protect our common global natural resources. The degradation occurring is a joint creation of developing and developed nations and there is a need to work together to get rid of the menace. Lots of commitments have been made in the Conference but there is a lack of political will on the part of those who were called up on to take action. He asked Ambassador Sha whether there will be action on what has been agreed upon in Rio+20. Ambassador Sha said the outcome of the Conference was not such that could please all but there will be opportunities to cooperate and work together.

Panelist Dr William Pyane said that there was lot of similarity between the recommendations of Rio+20 and those of the system wide Collaborative Research Project CRP 1.1 of the CGIAR for the drylands: reducing poverty and sustainable land management; contribution of small scale farmers to sustainable resource management; innovation systems; participation of youth and gender equity, etc. Thus the outputs of this Project will greatly contribute to the Sustainable Development Agenda as envisaged in Rio+20.

Co-chair Dr Zafar Adeel also thanked Ambassador Sha for his keynote presentation and he asked the participants for a forward-looking deliberation on the issues raised. There was a need to find appropriate answers to the five questions raised by Ambassador Sha. There is an opportunity with us to feed information from the scientific community to the policy makers so that progress in achieving SDGs could be made. With these comments, he opened the discussion to the floor.

Dr Kauser Malik, recognizing the differences in the interests of the participants in the global conventions, said that dialogue between different interest groups should continue. We should compare the outcomes of Rio+20 and of the other global conventions and continue to have discussions. The dialogue will help in identification of priority areas for work by the scientific community. We should also share the scientific achievements that have been made and which could be fed into the SD programs.

Dr Fawzi Karajeh was of the view that often the politicians do not pay heed to what the scientists suggest. In this respect it is good that some consensus has been reached in Rio+20 and there are a few points on which action could be initiated. Convergence and partnership of private sector, public sector, NGOs and other members of civil society is essential for making any head, but it is difficult because they all have different interests.

Dr Adel Aboulnaga said the SDGs provide good guidance to Governments and scientists, but implementation is a different matter and so much dependent on individuals. This however should not discourage the willing ones to make headway.

Ambassador Sha stressed the need for having a positive attitude. The MDGs and SDGs were very useful and considerable progress has occurred on achieving the targets of MDGs. We will have to work harder than in the past. The SDGs are much wider than MDGs and there are many very forward looking ideas. We should prioritize the goals and for each goal we must develop verifiable indicators.

Dr Shalendra Kumar said that to prevent degradation the custodians of the natural resources should be given some incentives. Only then will the policy implementation be possible.

Dr Pandi Zdruli said the interface between scientists and policy makers is very important. How the scientific information is communicated to the policy makers may determine the extent of and success in implementation.

Co-chair Dr Zafar Adeel, wrapping up the discussion, said that there was a need to identify critical gaps in scientific knowledge that would have bearing on the progress in achieving SDGs. The SDGs offer us opportunities to fill these gaps. 'The green economy' mechanism gives us opportunity to achieve SDGs as well as addressing the poverty and gender equity issues. We should also prepare ourselves for new and emerging challenges, which we still do not know. Technological innovations will be needed and we will have to mobilize scientific capacity, capital and other resources to face the future challenges. Partnerships will be key to success in these endeavors.

Concluding Session

Concluding Session Report

18. The Session was chaired by Prof. Dr Adel El-Beltagy, Chair of International Dryland Development Commission (IDDC). It was attended by all the participants of the Conference.

19. The following was the agenda:

    - Open-house Discussion:
        - Beijing Statement
        - General recommendations
    - Recognition
    - Closing remarks
    - Vote of thanks

20. Based on the recommendations emerging from various technical sessions the members of the Executive Committee of the ICDD developed a draft '**Beijing Statement**' which could be distributed widely to all stakeholders for information and further action in promoting sustainable development of drylands. It was distributed to all participants in advance so that it could be discussed and finalized in the Closing Session. The Chair person invited suggestions from the floor. Several suggestions were made. These were incorporated in the final version of the **Beijing Statement**, which is given in the end of this section (Box 1).

21. The Chairperson invited the participants to make **general recommendations** which would help in guiding the future course of action by the Commission, including organization of future conferences, and enhancing the achievement of the objectives of the Commission.

22. Following **suggestions/recommendations** were made with respect to the organization of the presentations in the Conference in the future:

    - There is a need to distinguish between desert transformation, development of dryland communities, and desertification control. An analysis of the papers presented and a suggested typology is given in the Table 1.
    - Sociological aspects and the importance of community should get greater attention.
    - Replication and scaling up of successful and proven approaches needs to be promoted and successful approaches should be show-cased in the IDCC's next conference.
    - Agro-ecosystems should be at the core. There is a need to put everything into a global context. Global change implies more than just global climate change. Economic, political and cultural changes occur every day.
    - Animal-based systems need better recognition because food and fibre production from drylands is so vital.

Box 1

11th International Drylands Development Conference, 18-21 March, China

Beyond 2015 – Beijing Statement

Drylands - comprising deserts, rangelands, rainfed croplands, wastelands, and some savanna woodlands - cover about 41 per cent of Earth's land surface and are inhabited by more than 2 billion people. More than 50% of the poor and malnourished of the world live in the dry areas and suffer from food insecurity, and socio-economic and socio-political instability. Many of these areas face severe land degradation, potentially undermining the productivity of these important ecosystems. Natural and semi-natural ecosystems are being degraded by the mismanagement of water resources, inappropriate land use practices and overgrazing. Increasing fuel prices are making agricultural inputs and operations more costly, reducing agricultural productivity, and increasing food prices. The impact of global climate change would worsen the situation. Therefore, there is an urgent need to pay attention to improving coping capacity of the people in the dry areas and minimizing vulnerability by developing knowledge-based adaptation and mitigation modalities through global cooperation. Hence, it is imperative that the post-2015 development agenda by the international community takes account of the challenges faced by over 2 billion people living in these drylands. Consolidated responses must undertake drylands development in a manner that adequately addresses water, food, feed, and energy security concerns and offer opportunities for economic development while respecting the rich and varied social and cultural heritages.

The Participants of the Conference, representing research and development community from 29 countries and 14 regional and international organizations, have come to the conclusion that this can be achieved in two ways:

- First, the sustainable development goals (SDGs) should maintain a sharp focus on issues that are of relevance to drylands: reducing poverty through sustainable land management, protecting livelihoods and ensuring human wellbeing, adequate management of scarce water resources, and providing incentives to governments for initiating proactive responses to land degradation. The notion of green economy may provide us a useful starting point for formulating such SDGs. In this new paradigm of sustainability, the notions of carbon footprint and water footprint must figure centrally within green economy policies. However, this must be balanced to become globally equitable.

- Second, countries and people must be resourced to meet with new and emerging challenges, the awareness of which has to be enhanced amongst all stakeholders. As climate change exposes us to unprecedented water stress and impacts on biodiversity, no region is more adversely impacted than drylands – and we must therefore work on building societal resilience against such new challenges. This can be achieved by: (a) developing scientific and technological resources and making them available to governments and other stakeholders in drylands developing countries; (b) mobilizing and further developing human and institutional capacity in developing countries, ensuring gender equity and empowerment, particularly around sustainable land, water and genetic resource management, adopting an agro-ecosystem approach; (c) mobilizing new capital, both in the public and private sectors, to develop institutions and infrastructure and sustainable renewable energy sources; and (d) introducing specific enabling policies and legislation.

- Need to recognize that most interventions involve land users foregoing income (often substantial) for several years. It may take 5-7 years to recoup the outlay.

- Greater attention should be given to land fragmentation. This is a major problem that is exacerbated by land tenure, inheritance laws and rising populations.

Table 1: Suggested typology of the papers presented in the 11th ICDD

Desert transformation	Desert adaptation	Desert technologies	Research* in/on/ for drylands
Irrigation in drylands	Improve crops	Alternative energy solar wind	Plant physiology/breeding
Biosaline agriculture	Amend soils	Desalination	C sequestration
Kubuqi desert case study	Improve WUE	Water recycling/ recovery	Physics of erosion
Taklamakan desert h'way	Improve livestock		
Desert encroachment control: • Mechanical – Checkerboards – Wind barriers • Biological – Aerial sowing			

**Research can be IN the drylands (as an outdoor laboratory), ABOUT the drylands (maybe from a desk in a city) or FOR the drylands. ICDDC needs to focus more on the last mentioned.*

23. Other **recommendations**, emanating from the presentations made in the Conference and some general recommendations included the following**:**

- For development of viable and sustainable desert communities, based on a particular water basin and reclaimed desert land, there needs to be not only revived and stable agricultural systems, but also industrial , agro-industrial and urban industry base. This means, a range of companies should be involved, not just one, and there should be integrated development, not one sided approach.

- The needs of the stakeholders – villagers, farmers, family members – should be taken into account in any interventions in the drylands. It should be recognized that the stakeholders might have other prioritie/pressures than those involved in any intervention.

- An interesting example of a commercial model for increasing food and energy security, and environment and health protection of poor communities by integrating small farmer-based farming, bio-processing, and retail distribution of food and clean energy products was presented in Mozambique. The model could be of great value for use in other dry areas of Africa, Asia and Latin America, where subsistence farming by small-scale farmers is common and poverty is forcing the people to degrade their natural resource base.

- The special session on Dryland Systems provided information on the scope, dimension and methodology of implementation of this multi-partner integrated project. The participants greatly appreciated the initiative as it would complement and promote the objectives of ICDD. The participants, however, hope that the activities under the project will start soon and these will build on the knowledge already developed on the subject.

- During future conferences serious consideration should be given to bringing in 3 to 5 local dryland farmers/ practitioners to share their experiences with the forum.

- Any production and conservation strategies for dryland marginal environments should be based on sound eco-geographical studies and choice of relevant plant species. This will also ensure that in addition to economic gains environmental benefits will follow.

- Use of marginal lands (e.g. salinity/sodicity affected) with suitable halophytes should be promoted as an integrated package with advanced production technology (include smarter irrigation techniques using recycled water) for forage and biofuel production

- The water use efficiency or water productivity was higher with deficit irrigation than full irrigation or rainfed. Thus deficit irrigation should be disseminated to farmers. However, as there is no leaching of salts under deficit irrigation, there is concern of long-term productivity of deficit irrigation. Therefore , long-term experiments or evaluation of water use efficiency considering leaching requirement should be carried out.

- Opportunities exist to improve water use efficiency through land management even in the face of climate change.

- There is a need for better determination of causes and better management practices for controlling wind erosion in major desert regions or environmentally sensitive areas.

- Identification of new adaptive traits in wheat germplasm for future climate change is necessary.

- Osmotic adjustment and stomatal movement control could be useful traits in developing adaptation to salinity and sodicity.

- More case studies, success stories should be highlighted.

- There are extensive research results and successful development projects for improvement of the grazing lands in the dry areas, which could be up-scaled to make a difference in areas of similar ecologies elsewhere. Examples are water harvesting techniques for seeding shrubs and improving the soil nutrient status to improve land productivity for livestock in areas where moisture is not a limiting factor.

- There is great scope for south-south collaboration as illustrated by significant increases in productivity in the dryland agriculture in Kenya by introduction of dryland soil and water management techniques developed for China.

24. Recognition: The International Dryland Development Commission recognized the following individuals for their contribution to the dryland research and development and for promoting the objectives of the Commission:

- Founders:
  - Prof. Adli Bishay
  - Prof. Dr. Adel El-Beltagy
- ***Life-time achievement*:**
  - Prof. Iwao Kobori
  - Academician Dzhamin Akimaliev
  - Prof. Dr. Shinobu Inanaga
  - Prof. Dr. Gareth Wyn Jones
  - Dr. Mahmoud Solh
  - Prof. Dr. Mohan Saxena
- Outstanding research contributions:
  - Prof. Dr. Wang Tao
  - Prof. Dr. Stephen Wells
  - Prof. Dr Atsushi Tsunekawa
  - Prof. Dr. Ayman Abou Hadid
  - Dr. Zafar Adeel
  - Dr. Theib Oweis

25. Concluding remarks:

8.1. Professor Wang Tao expressed his great satisfaction on the way the Conference had progressed. He thanked the Chinese Academy of Sciences for its patronage to the Conference. He expressed his appreciation of his colleagues for their dedication and team work in attending to the needs of the participants and making various arrangements for the Conference. He thanked the participants for the level of professionalism they brought to deliberations which made the Conference so successful.

8.2. Professor Adel El-Beltagy reiterated the need for urgent attention to preventing desertification and promoting sustainable dryland development in view of the global changes already occurring. There was a need for the politicians and other stake holders to move fast with policy reforms and allocation of resources for sustainable development of dry areas as we did not have the luxury of letting the business go as usual. Community participation in these efforts was essential and for this enabling environment had to be created, particularly for marginalized and poor, and consideration for gender equality. The impact of climate changes at local level should be properly assessed so that effective strategies for coping with weather aberrations and other adverse factors associated with the climate change could be developed and made available to the communities. Role of science and technology was enormous and the developed countries had to help their developing partners with tools and capacity building to permit realistic assessment of impacts at local levels and devising ways to cope with these. Need for promotion of renewable energy resources was urgent. Adaptation strategies are crucial for poor and disempowered people. Efforts on adaptation should go hand in hand with mitigation.

These are the messages that have emerged from the deliberations of this Conference and these will be disseminated to all concerned through the "Beijing Statement".

8.3. Professor Mohan Saxena proposed the vote of thanks. He thanked the Chinese Academy of Sciences (CAS) for hosting the Conference and requested Prof Wang Tao to convey the gratitude of the International Dryland Development Commission to Prof. Chunli Bai, President of CAS for his patronage and support to the Conference. He thanked Prof. Wang Tao himself for serving as an outstanding leader of the host country team, which worked so meticulously in making all the necessary arrangements for the Conference to make it a grand success. He particularly thanked Prof. Xue Xian for her untiring efforts, right from the time the first Circular of the Conference went out to the potential participants till the conclusion of the Conference, in ensuring that the Conference ran without any snags. Prof. Xian, under the guidance of Prof. Wang Tao, worked very closely with the Executive of International Dryland Development Commission in developing all the technical material and arranging the facilities needed for efficient conduct of various technical sessions. Prof. Saxena also thanked Ms. Cuiling Lan, who so effectively took care of all the logistic arrangements of the Conference. She endeared herself to all the participants by providing answers to all their questions and helping them in meeting the deadlines of the Conference. Prof. Saxena expressed his great appreciation for the contributions of Ms. Aida Ghazi in the planning and the conduct of the Conference and for being such a dependable support for the International Dryland Development Commission. The assistance of Ms. Sahar Saleh in managing the financial matters of the Commission was also greatly appreciated. Prof. Saxena thanked all the session co-chairs for efficient conduct of their respective sessions. He thanked all the participants for their deliberations in the Conference. In the end, he proposed a hearty vote of thanks to the Chair of the Conference for his foresight and leadership that has kept the International Dryland Development Commission going from strength to strength.

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Eleventh International Dryland Development Conference Commitees

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