



Climate Change and Sustainable Agro-ecology in Global Drylands

EDITED BY ADEL S. EL-BELTAGY,
RATTAN LAL AND KAUSER MALIK



Climate Change and Sustainable Agro-ecology in Global Drylands

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Edited by Adel El-Beltagy, Rattan Lal and Kauser Malik

Climate Change and Sustainable Agro-ecology in Global Drylands

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CABI is a trading name of CAB International

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A catalogue record for this book is available from the British Library, London, UK.

ISBN-13: 9781800624856 (hardback)
9781800624863 (ePDF)
9781800624870 (ePub)

DOI: 10.1079/9781800624870.0000

Commissioning Editor: David Hemming
Editorial Assistant: Emma McCann
Production Editor: Shankari Wilford

Typeset by Straive, Pondicherry, India
Printed and bound in the UK by CPI Group (UK) Ltd, Croydon, CR0 4YY

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Prof. Dr. Kauser Abdulla Malik (Pakistan) is former Federal Minister of National Food Security and Research (since 2023); Distinguished National Professor of Biotechnology, currently leading agricultural biotechnology programmes at KAM School of Life Sciences at Forman Christian College, Lahore, since 2008. He was Chairman of Pakistan Agricultural Research Council (1998–2001); Member, Biosciences, Pakistan Atomic Energy Commission (2001–2006); Member, (Food Agri) Planning Commission, Islamabad (2006–2008); Head of Soil Biology Division of Nuclear Institute for Agriculture and Biology (NIAB) (1971–1992); founding Director of the National Institute for Biotechnology and Genetic Engineering (NIBGE) at Faisalabad (1992–1998); Member, Standing Advisory Group for Nuclear Applications (SAGNA) of IAEA for 9 years; Member, Board of Trustees of International Foundation of Science (IFS), Stockholm; BoG Member, International Institute for Applied Systems Analysis (IIASA), Vienna. His earlier research was on biology of saline soils and biodynamics of organic matter formation. These led to the development of bio-saline agriculture technology which was later picked up by FAO/IAEA Joint Division and implemented in several countries of the Middle East. He was a pioneer in reporting associative nitrogen fixation associated with roots of non-legumes, which led to the development of commercial biofertilizers for cereal crops. Subsequently, he developed an interest in plant biotechnology and in plant biotechnology related to biofortification and transgenic wheat for salt tolerance, drought tolerance, and increased fertilizer-use efficiency. **Awards:** 3 civil awards by the President of Pakistan for his services to science; Fellow of Pakistan Academy of Sciences (PAS) and The World Academy of Sciences (TWAS). **Publications:** over 250 research articles published in peer-reviewed journals; edited 5 books.

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Dr. Anuradha Agrawal (India) is Project Director of ICAR-Directorate of Knowledge Management in Agriculture (DKMA), New Delhi, and the National Coordinator in the National Agricultural Higher Education Project (NAHEP), a joint mega-project of the Indian Council of Agricultural Research (ICAR) and World Bank. She has more than 30 years' experience in the area of plant genetic resources (PGR) management, with special reference to use of biotechnology in the *ex situ* conservation of 'difficult-to-conserve crops'. While working as Officer-in-Charge (2017–2022) at

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Dr. Juan Andrés Quincke (Uruguay) graduated as agronomist from the College of Agriculture at Udelar (Uruguay) and obtained his MSc and PhD degrees at the University of Nebraska-Lincoln (USA); Principal Researcher at the National Agricultural Research Institute (INIA, Uruguay) in the field of soil fertility and management; Member, INIA's long-term experiments team (Plataforma Agroambiental); leading scientist of the old Crop-Pasture Rotations Experiment at INIA La Estanzuela. Specific research topics include soil carbon dynamics under agricultural management practices, soil tests for phosphorus management, and soil erosion.

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Foreword: Climate Change and Sustainable Agro-ecology in Global Drylands

Despite growing political momentum, the world remains deep in the triple planetary crisis of climate change, nature and biodiversity loss, and pollution and waste. This triple crisis threatens the well-being of current and future generations. Food systems are at the heart of this crisis, as both a driver and victim of environmental change. Climate variability and extreme weather have already slowed global agricultural productivity growth, with further disruption to come.

In this light, *Climate Change and Sustainable Agro-ecology in Global Drylands* is a timely work; it highlights the importance of pursuing innovative pathways that will make agriculture in drylands sustainable. These ecosystems cover about 40% of the land area and may expand to cover 50% of the land area by 2100 as climate change worsens. Building local adaptation in drylands is therefore critical. This book presents important insights and analysis from a senior and distinguished group of scientists, highlighting experiences and outlining an important set of innovative adaptation strategies to support the 2.5 billion people who inhabit dryland ecosystems.

The authors cast their net far and wide, looking at practices in Africa, the Americas, China, India and Pakistan. The articles look at the potential of increasing carbon stocks in dryland biomass and soils to slow climate change and create income for farmers through payments. They look at using smart phones and AI to modernize agriculture and make it more efficient, using plant genetic resources to boost climate adaptation in drylands, how to deploy water-smart irrigation and rainwater harvesting, and so much more.

Such practices safeguard people, biodiversity, and crucial ecosystem services, especially in environments that are highly vulnerable to climate change. The transition towards sustainable food systems and a climate-adapted future will depend on the widespread adoption of such innovative net-positive agricultural practices and technologies.

This book is a testament to the scientists and local stakeholders who have dedicated much of their lives to this cause and can serve as a source of knowledge and a catalyst for change. By following their lead, we can, together, protect and nurture the planet that sustains us all.

Inger Andersen

*Under-Secretary-General of the United Nations and Executive Director
of the United Nations Environment Programme*

Preface: The Day after COP28 – The Road Ahead: Climate Change and Sustainable Agro-ecology in Global Drylands

This book deals with an essential topic: climate change and sustainable agro-ecology in global drylands. It is an exceptionally large effort by an eminent group of scientists and development specialists to address the challenges of saving the lives and livelihoods of the poor and vulnerable, especially in the drylands of the world, where fragile ecosystems are particularly exposed to the increasingly visible consequences of climate change. These drylands cover about 40% of the Earth's surface and are home to about 40% of the world's population, of whom some 80% are the poorest and most vulnerable of the human family.

An introductory and a concluding chapter bracket the contents of the book and are contributed by the editorial board that guided the production of the materials in these diverse chapters. The concluding chapter is appropriately titled 'The Day after COP28', not only referring to the time the book is being issued, but also to this moment in humanity's struggle to respond adequately to the challenge of climate change.

The day after COP28 is indeed a proper moment to reflect on how far we have come in the last three decades, and how much remains to be done. It reminds us all that climate change is a global problem that does not recognize political borders or societal boundaries, and that it requires a truly global collective effort by all the nations of the world.

We cannot overstate how serious the situation is. We are facing an existential challenge. The IPCC report (AR6) of 2021 shows that:

...we've currently reached 1.1°C above the average temperatures from 1850–1900. Not in 125,000 years has earth seen a time period with such a high average temperature for such a prolonged period of time, indicating that this is more than just a natural heat spike...This is coupled with reporting that atmospheric CO₂ is at a 2,000,000-year peak and that other greenhouse gasses like methane and nitrous oxide are at 800,000-year peaks.

Everyone now recognizes that global warming is due to the accumulation of greenhouse gases (GHG) in the atmosphere, mainly CO₂ but also methane and nitrous oxide. That means that we must stop adding to these GHGs, and then seek their reduction if we are to keep the world's average surface temperature to no more than 1.5 degrees warmer than pre-industrial levels by 2100. That implies reaching net-zero emissions by 2050. That, in turn, requires that we reduce annual emissions by about 45% come 2030. Keeping global warming below 1.5 degrees is the commitment that 195 countries took in the Paris Agreement of 2015, and yet we are continuing to increase our global emissions every year. Indeed, in 2022, global energy-related CO₂ emissions grew by 0.9%, or 321

million tons, reaching a new high of more than 36.8 billion tons. So, we are not on track to fulfil our 2015 Paris Agreement pledge, and mitigation of GHG emissions is certainly not on track.

But beyond mitigation, we must also focus on adaptation and resilience, especially in the global south, where so many of the poor and vulnerable members of the human family live, and who are suffering the already visible consequences of climate change. This requires support to implement policies and programmes to promote adaptation and nurture resilience to the devastation of climate change. That is especially true for the drylands that cover 40% of the land area on the planet and are inhabited by some 40% of the world's population, but where we find some 80% of the poorest and most vulnerable of the human family. They are the ones who are suffering most from the consequences of this global existential challenge, even though they contributed least to the creation of the problem. We made a major step in that direction in COP27 when we adopted the idea of a 'Loss and Damage Fund' to support the necessary funding for adaptation and resilience in the global south. This book covers many of the aspects of both the challenges that these poor vulnerable populations face, and what can be done to respond to them.

Where are we as we emerge from COP28?

It is clear that we are not on track to fulfilling our obligations as defined in the Paris Agreement of 2015, and the Nationally Determined Commitments (NDCs) that followed it. These NDCs themselves, even if fully implemented, would not have been enough to reach our Paris Agreement pledge. We are falling short.

Fossil fuels continue to be the prime cause of the growing emissions of GHGs. However, for the first time, the countries agreed to a statement about fossil fuels, accepting the wording 'transition away from fossil fuels', a much weaker statement than 'phasing out fossil fuels', which was the wording advocated by many of the climate activists present. In addition, the adopted wording came without any milestones or time horizons.

Another positive development at COP28 has been the attention given to the food and agriculture sector. For the first time, COP28 allocated an entire day to discussing the transformation of food systems, and it was only the second time the conference included a pavilion dedicated to food systems. The food and agriculture sector does contribute to the world's total emissions. But we believe that the transformation of the food and agriculture sector, from being a contributor to GHGs to being part of the solution, can emerge as a major force for carbon capture and sequestration (CCS). After all, plants are nature's system of CCS! A transformed sector, reducing or abolishing the enormous wastage that now exists as we move towards science-based precise agriculture and climate-smart agriculture (CSA), will also noticeably increase the efficiency and effectiveness of the sector to move towards the goal of abolishing hunger in the world.

Also positive in this domain is that, following this progress, countries including Brazil, Norway, Sierra Leone, Cambodia and Rwanda established the Alliance of Champions for Food Systems Transformation. This alliance aims to ensure that nations are responsible for reporting developments in this sector. Supporting these efforts, the UN's Food and Agriculture Organization (FAO) unveiled its strategy, designed to offer a worldwide perspective on transformation; more specific regional analyses, financial projections, and national strategies are now expected in future conferences.

The contents of this book cover the intense and urgent collective action required to tackle the dual challenges of the influence of climate change on food security as well as the impact of our food systems on climate change. It is particularly timely to be coming out after COP28.

Methane, significantly more potent than carbon dioxide in warming the atmosphere during its initial decade, contributes to around one third of current global warming, as per the IPCC. However, it dissipates in a few decades as opposed to CO₂ which takes centuries to dissipate. Thus, urgent and decisive action to eliminate methane emissions would have a relatively fast impact on the emissions

problem. COP28 recognized the importance of stopping methane emissions but did not really add meaningfully to the timing of implementing the necessary measures.

Given methane's short lifespan, yet high impact, immediate action to reduce emissions is critical for achieving global climate objectives and mitigating both immediate and long-term effects of climate change. While COP28 saw encouraging developments regarding methane, the fundamental problem of dependence on pollutant fuels persists, and mere efficiency improvements, though beneficial, are insufficient.

Human health, and the intricate links between it and the health of the planet, were also broached in COP28. Indeed, COP28 dedicated an entire day to exploring how climate change affects human health. It also brought together health ministers who participated with their environmental counterparts for the first time. Finally, over 120 countries endorsed the Climate and Health Declaration, underscoring the need for all countries to look at the links between climate change and human health in their national plans.

COP28 also looked at financing. Another positive outcome, was the confirmation of the creation of the Loss and Damage Fund, aimed at providing financial support to low- and middle-income countries (LMICs) grappling with the effects of climate change, such as severe weather events and rising sea levels, and even the start of some modest funding for that new facility. However, the funding provided is still way short of what is required and placing it within the World Bank was not what a number of the LMICs wanted, as they consider that institution too closely associated with the G7 countries.

In fact, the \$700 million provided for the fund is a mere 0.2% of what experts estimate is necessary to cover all damages caused by climate change.

That, of course, highlights that approaching the financing issue in a new and innovative approach is desperately needed. We estimate that the total financing required will be around 5–7 trillion dollars, annually, for the coming decade or more. This sum cannot be reached by the conventional approaches when total Official Development Assistance (ODA) from all OECD countries for all sectors is a mere 200 billion dollars annually. Therefore, finance for climate change, covering emissions, adaptation, and resilience, remains high on the agenda for any future discussion of climate change.

Much of the material in this book is very timely as we prepare for COP29 in Baku, Azerbaijan, in late 2024. May the collective experience of all the specialists who contributed to the multifaceted discussions reported in this volume take us a step closer to help humanity curb the negative orientations and advance the caring and nurturing approaches for the poor and the vulnerable. May it help us to develop the necessary science-based policies and evidence-based regulations that the world must apply to rise to the challenge of climate change and return to the path of sustainable development.

Ismail Serageldin

Honorary President of the IDDC. Former VP of the World Bank. Former Chair of the CGIAR.

Acknowledgments

This book is the result of collaborative efforts from a diverse group of authors spanning various domains and agro-ecological zones within dry areas worldwide. The collective contributions of 53 authors, representing more than 51 institutions across 16 nationalities, have significantly enriched the content of this book, and we extend our sincere gratitude to each of them.

We express our appreciation to Dr. Inger Andersen, Under-Secretary-General of the United Nations and Executive Director of the United Nations Environment Programme (UNEP), for graciously contributing the Foreword to this publication. Additionally, our heartfelt thanks go to Dr. Ismail Serageldin, Honorary President of the IDDC, Former Vice President of the World Bank, and Former Chair of the CGIAR, for contributing the Preface.

A special acknowledgment is extended to Dr. Mohan Saxena, Executive Secretary of the International Dryland Development Commission (IDDC), for his invaluable contribution to this project.

We wish to recognize the pivotal role played by Eng. Aida Ghazi, Former Under-Secretary of Extension & Training, Ministry of Agriculture and Land Reclamation, Egypt, who skillfully coordinated the task leading to the completion of this book. Our sincere gratitude also goes to Ms Dina Taha, illustrator, UX/UI designer and graphic designer, for her significant input and contribution during the revision process. Dr. Hanaa Adly is acknowledged for her valuable insights and assistance in processing materials, while Dr. Sameh Hassanein is thanked for his technical expertise.

The collective efforts of these individuals have played an integral role in shaping and refining the content of this book, and we are truly grateful for their dedication and expertise.

The editors would also like to thank the team at CABI, including David Hemming, Emma McCann, Shankari Wilford and Marion Doy.

The Editorial Board

List of Abbreviations and Acronyms

%	- Per cent
>=	- Greater than or equal to
°C	- Degrees Celsius
°E	- Degrees East
°N	- Degrees North
1 Faddan	= 1.04 acres
13 T	- Cotton, genetically modified
¹³ C	- Carbon-13
²³⁰ Th	- Thorium-230
²³⁴ U	- Uranium-234
²³⁸ U	- Uranium-238
ABA	- Absciscic acid
ABS	- Access and benefit sharing (for genetic resources)
ACC	- Anthropogenic climate change
ACIAR	- Australian Centre for International Agricultural Research
ACs	- Agriculture cooperatives
AE	- Agro-ecological
AEZs	- Agro-ecological zones
AF	- Adaptation fund
AFD	- Agence Française de Développement
AGERI	- Agriculture Genetic Engineering Research Institute
AGMERRA	- AgMIP dataset by Modern-Era Retrospective Analysis for Research & Applications
AgMIP	- Agricultural Model Intercomparison and Improvement Project
AI	- Artificial intelligence
AIB	- Allied Irish Bank
ALRC	- Arid Land Research Center, Japan
ALYM	- African League of Young Masters
AMV	- Alfalfa mosaic virus
API	- Aquaculture and photo-voltaic integration
APSIM	- Agricultural Production Systems Simulator
AR	- Assessment Report of IPCC
AR4D	- Agricultural research for development
ARC	- Agricultural Research Center

ARDC	- Agricultural Research & Development Council
B	- Billion
BD	- Bulk density
BGM	- Botrytis grey mold
BWYV	- Beet Western Yellow Virus
C	- Carbon
Ca	- Calcium
CA	- Conservation agriculture
Ca ²⁺	- Calcium ion
CAADP	- Comprehensive Africa Agriculture Development Program
CAS	- Conservation agriculture systems
CASI	- Conservation agriculture-based sustainable intensification
CBA	- Community-based adaptation
CBD	- Convention on Biological Diversity
CC	- Climate change
CCAFS, CCFS	- Climate change agriculture and food security
CCS	- Carbon capture and sequestration
CECA	- Centre of Excellence for Conservation Agriculture
CF	- Carbon farming
CFAES	- College of Food, Agricultural, and Environmental Sciences
CFS	- Committee on World Food Security
CGIAR	- Consultative Group for International Agricultural Research
CGR	- Crop genetic resources
CGREA	- Commission on Genetic Resources for Food and Agriculture
CH ₄	- Methane
CI	- Concentration index
CIMMYT	- International Maize and Wheat Improvement Center
CIS	- Climate information system
CLAC	- The Central Laboratory for Information Center
cm	- Centimeters
CO ₂	- Carbon dioxide
COP	- Conference of the Parties (to the UN Framework Convention on Climate Change)
COP27	- 27th Conference of the Parties
CoPs	- Community of Practitioners
CpCSV	- Chickpea Chlorotic Stunt Virus
CRA	- Climate-resilient agriculture
CRISPR	- Clustered regularly interspaced short palindromic repeats
CRISPR/Cas9	- The fundamental technology for genome editing
CRV	- Climate-resilient village
CSA	- Climate-smart agriculture
CSDs	- Civil society organizations
CSE	- Center for Science and Environment
CT	- Conventional tillage
CTCN	- Climate Technology Centre and Network
CWANA	- Central and West Asia & North Africa
CWR	- Crop wild relatives
DACP	- District Agricultural Contingency Plan
DAFW	- Department of Agriculture & Farmers Welfare
DARE	- Department of Agricultural Research & Education
DHA	- Dehydrogenase activity

DIIVA-PR	- Dissemination of interspecific ICARDA varieties and elites through participatory research
DNA	- Deoxyribonucleic acid
DREP	- Dehydration responsive element binding
DRR	- Disaster risk reduction
DSR	- Direct seeded rice
DSS	- Decision support systems
DSSAT	- Decision support system for agro-technology transfer
EEZ	- Exclusive Economic Zone
EGP	- Eastern Gangetic Plains
ESCWA	- Economic and Social Commission for Western Asia of the United Nations
ESs	- Essential ecosystem services
EST	- Expressed sequence tag
EU	- European Union
FAO	- Food and Agriculture Organization of the United Nations
FAS	- Food and agriculture sector
Fig.	- Figure
FIGS	- Focused identification of the germplasm strategy
FMNR	- Farmer-managed natural regeneration
FP	- Flat planting
FSFPS	- Food security and food production systems
FSN	- Food security and nutrition
FW	- Fusarium wilt
FYM	- Farmyard manure
g	- Grams
G20	- Group of Twenty
GBF	- Global Biodiversity Framework
GCC	- Global carbon cycle
GCF	- Green Climate Fund
GCM	- General circulation model
GCM	- Global climate models
GCSAR	- General Commission for Scientific and Agricultural Research
GDLs	- Global drylands
GDP	- Gross domestic product
GERD	- Grand Ethiopian Renaissance Dam
GEWEX	- Global energy and water exchanges
GEAR	- Global Forum on Agricultural Research
GGP	- Global Gene Bank Partnership
GHG	- Greenhouse gas
GIM	- Green India Mission
GIS	- Geographic information system
GM	- Genetically modified
Govt	- Government
GPP	- Gross primary production
GPS	- Global positioning system
GRDC	- Grains Research and Development Corporation
GS	- Genomic selection
Gt C yr ⁻¹	- Gigatonnes of carbon per year
GVA	- Gross value added
GW	- Global warming
GWAS	- Genome-wide association study
GWP	- Global warming potential

H ₂ O	- Water
ha	- Hectare
HEIS	- High-efficiency irrigation systems
HFCs	- Hydrofluorocarbons
HKH	- Himalayan-Karakoram-Hindukush
HLI	- Heat Load Index
HLPE	- High-level panel of experts
HS	- Heat stress
IAC	- International Agrobiodiversity Congress
IBPES	- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ICAR	- Indian Council of Agricultural Research
ICARDA	- International Center for Agricultural Research in the Dry Areas
ICC	- India Climate Collaborative
ICCIP	- International Climate Change Information Program
ICLARM	- International Center for Living Aquatic Resources Management
ICRISAT	- International Crops Research Institute for the Semi-Arid Tropics
ICT	- Information and communication technology
IDDC	- International Dryland Development Commission
IEA	- International Energy Agency
IFAD	- International Fund for Agriculture Development
IGP	- Indo-Gangetic Plain
IICA	- Inter-American Institute for Cooperation on Agriculture
IITA	- International Institute of Tropical Agriculture
ILO	- International Labor Organization
INCCA	- Indian Network for Climate Change Assessment
INIA	- National Agricultural Research Institute
INM	- Integrated nutrient management
INR	- Indian rupee
IoT	- Internet of Things
IPCC	- Intergovernmental Panel on Climate Change
IPM	- Integrated pest management
IPPC	- International Plant Protection Convention
ISAAA	- International Service for the Acquisition of Agri-biotech Applications
ISRO	- Indian Space Research Organization
ISSM	- Integrated soil-crop system management
IT	- Information technology
ITPGREA	- International Treaty on Plant Genetic Resources for Food and Agriculture
IUCN	- International Union for the Conservation of Nature
IWM	- Integrated water management
K	- Potassium
K ⁺	- Potassium ion
kg	- Kilograms
km	- Kilometers
KUSUM	- Kisan Urja Suraksha evam Utthaan Mahaabhiyan
LDCs	- Least-developed countries
LICs	- Low-income countries
LLL	- Laser land leveling
LMIC	- Low- and middle-income countries
m	- Meter
M	- Million
MALR	- Ministry of Agriculture & Land Reclamation

MENA	- Middle East and North Africa region
MERRA	- Modern-Era Retrospective Analysis for Research & Applications
Mg	- Magnesium
Mg	- Megagram
mg	- milligrams
Mg ²⁺	- Magnesium ion
mha	- Million hectares
MIDH	- Mission for Integrated Development of Horticulture
mm	- Millimeters
MoEFCC	- Ministry of Environment, Forest, and Climate Change
MRB	- Mechanized raised bed
MT	- Million tonnes
MW	- Maize-wheat
N	- Nitrogen
N ₀	- Neutron
N ₁₃₅	- Nitrogen-135
N ₁₈₀	- Nitrogen-180
N ₂ O	- Nitrous oxide
N ₄₅	- Nitrogen-45
N ₉₀	- Nitrogen-90
Na ⁺	- Adsorb sodium
NAARM	- National Academy of Agricultural Research Management
NABARD	- National Bank for Agriculture and Rural Development
NAFCC	- National Adaptation Fund for Climate Change
NAPCC	- National Action Plan on Climate Change
NARES	- National Agricultural Research and Education System
NARS	- National Agricultural Research System
NASA	- National Aeronautics and Space Administration
NBAIR	- National Bureau of Agricultural Insect Resources
NBIAM	- National Bureau of Agriculturally Important Microorganisms
NBM	- National Bamboo Mission
NCCS	- National Climate Change Strategy
NDCs	- Nationally determined contributions
NEI	- Not elsewhere included
NEP	- Net ecosystem productivity
NFSM	- National Food Security Mission
NFT	- Non-fungible token
NGB	- National Gene Bank
NGIC	- Nizami Ganjavi International Center
NGO	- Non-governmental organization
NH ₃	- Ammonia
NH ₄ ⁺	- Ammonia ion
NICRA	- National innovations on climate-resilient agriculture
NIDIS	- National Integrated Drought Information System
NIE	- National implementing entity
NLM	- National Livestock Mission
NMSA	- National Mission for Sustainable Agriculture
NOAA	- National Oceanic & Atmospheric Administration
NPV	- Net return value
NT	- No-till
NTC	- No-till cropland
NTS	- No-till system

OECD	- Organization for Economic Co-operation & Development
OFWM	- On-farm water management
OR-N	- Organic and synthetic nitrogen fertilizers
P	- Phosphorus
PA	- Precision agriculture
PCR	- Polymerase chain reaction
PDMC	- Per Drop More Crop
PFCs	- Perfluorocarbons
Pg	- Petagram
Pg C year ⁻¹	- Petagram of carbon per year
PGR	- Plant genetic resources
PIC	- Pedogenic inorganic carbonates
PKVY	- Paramparagat Krishi Vikas Yojana
PMFBY	- Pradhan Mantri Fasal Bima Yojana
PMKSY	- Pradhan Mantri Krishi Sinchayee Yojana
QTL	- Quantitative trait loci
R4D	- Research for development
RACC	- Regional Action on Climate Change
RAP	- Representative agricultural pathways
RAPD	- Random Amplified Polymorphic DNA
RAS	- Recirculating aquaculture system
RCM	- Regional climate model
RCP	- Representative concentration pathway (IPCC)
RDF	- Recommended dose of fertilizers
RH	- Relative humidity
RKVY	- Rashtriya Krishi Vikas Yojana
RMP	- Recommended management practice
RUE	- Rain-use efficiency
RW	- Rice-wheat
RWH	- Rainwater harvesting
RWP	- Rainwater productivity
S	- Sulfur
SADS	- Sustainable Agriculture Development Strategy
SAPCC	- State Action Plan on Climate Change
SDGs	- Sustainable Development Goals
SDI	- Sub-surface drip-irrigation
SDS	- Sand dust storms
SF6	- Sulfur hexafluoride
SFDRR	- Sendai Framework for Disaster Risk Reduction
SFS	- Sustainable food systems
SH	- Soil health
SHM	- Soil-health management
SI	- Supplemental irrigation
SIC	- Soil inorganic carbon
SICLU	- Sustainable intensification of cultivated land use
SIDS	- Small island developing states
SLM	- Sustainable land management
SLR	- Sea-level rise
SMBC	- Soil microbial biomass carbon
SNP	- Single nucleotide polymorphisms
SOC	- Soil organic carbon
SON	- Soil organic nitrogen

SPM	- Summary for policymakers of IPCC
SQI	- Soil Quality Index
SRB	- Surface radiation budget
SRFSI	- Sustainable and resilient farming systems intensification
SRI	- System of rice intensification
SSA	- Sub-Saharan Africa
SSF	- Small-scale fisheries/fishing
SSNM	- Site-specific nutrient management
SSR	- Simple sequence repeats
STC	- Strip-tilled cropland
STS	- Science & Technology for Society Forum
STS	- Socio-technical systems
T Sh.	- Tanzania shilling
TAAS	- Trust for Advancement of Agricultural Sciences
TAAT	- Technology for Africa Agriculture Transformation
TEC	- Technology Executive Committee
Tg	- Teragram (= million ton)
THI	- Temperature humidity index
TVET	- Technical & vocational education & training
TYLCV	- Tomato Yellow Leaf Curl Virus
US	- United States
USA	- United States of America
UGL	- Ungrazed native grassland
UN	- United Nations
UNCCD	- United Nations Convention to Combat Desertification
UNDP	- United Nations Development Program
UNEP	- United Nations Environment Program
UNESCO	- United Nations Educational, Scientific and Cultural Organization
UNFCCC	- United Nations Framework Convention on Climate Change
UNICEF	- United Nations International Children's Emergency Fund (now officially United Nations Children's Fund)
UNIDO	- United Nations Industrial Development Organization
UN-SDG	- United Nations Sustainable Development Goal
UNU	- United Nations University
US \$	- United States dollar
USAID	- United States Agency for International Development
USDA	- United States Department of Agriculture
USGCRP	- United Nations Global Change Research Program
VCRMCM	- Village-level climate risk management committee
WANA	- West Asia and North Africa
WAPDA	- Water and Power Development Authority
WBT	- Wet bulb temperature
WEF	- World Economic Forum
WG	- Working group
WHO	- World Health Organization
WMO	- World Meteorological Organization
WP	- Water productivity
WPI	- Water Productivity Index
WRKY	- Transcription factor 'worky'
WUE	- Water-use efficiency
Yr	- Year
ZT	- Zero tillage

1 Introduction

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Drylands are home to nearly 2.5 billion people with 80% of the Earth's poorest people living in dryland developing countries. The inhabitants of drylands are facing unprecedented challenges to their sustainability because of climate change.

Global drylands are highly vulnerable to anthropogenic climate change, and land area under drylands may expand from 41%, presently, to 50% of the Earth's surface by the year 2100. Drylands include 45% of agricultural land, which will be affected by climate change in aggravating prevalence of undernutrition and malnutrition (El-Beltagy *et al.*, 2005; Sivakumar *et al.*, 2013) because of adverse effects on the quantity and quality of food production in these regions. The world population is currently 8.1 billion and is projected to reach 9.8 billion by 2050. A radical transformation of the world's food systems will be needed. Seventy per cent of the increase in world population between now and 2050 will be in 24 of the poorest countries of the world. Meanwhile, the projected increase in temperature beyond 1.5°C, which may reach 3°C, will reduce food production by 20–50%.

The objective of this book is to adopt a holistic approach to sustainable management of drylands to make agriculture drought-resilient and to sustain the livelihood of the vulnerable inhabitants (Traylor *et al.*, 1999). Eminent scientists from around the world have been invited to share their knowledge and experiences for adaptation and mitigation of anthropogenic climate

change through innovation in sustainable management of natural resources of water, soil, and biodiversity (crops, livestock, fisheries).

Time is of the essence as the Earth's average surface temperature in 2022 was the fifth warmest on record. Continuing the planet's warming trend, global temperature in 2022 was 1.06°C above the average for NASA's baseline period (1951–1980) and confirmed by NOAA Record (NOAA, 2023).

In addition, NASA clocks stated that July 2023 was the hottest month on record since 1880 (Wong, 2023). Tollefson (2023) stated that Earth's hottest month happened in July and that heatwave projections could see a 1.5°C rise, surpassing it in a matter of years at around 2°C of warming. This is likely even if governments meet their climate commitments. Based on current policies alone, climate scientists estimate that temperatures could rise nearly 3°C in this century. In each of these scenarios, models project that many places on Earth could experience 30–40 extra days each year above 35°C, affecting public health and ecosystems globally (Tollefson, 2023).

Launched in 2001 and involving more than 1300 leading scientists, the Millennium Ecosystems Assessment is a study of how humans have altered ecosystems and the impact on human well-being. Integrating findings at local, regional, and global scales, it is the first truly comprehensive picture of the health of the planet (Millennium Ecosystem Assessment, 2005).

The anticipation that climate change will have major impacts on agro-ecosystems requires continuous dynamic assessments, globally, regionally, and at the local level where the major action of adaptation would have to occur. The assessment will require international cooperation, national capacity building, and a solid early-warning system.

This book presents a cross-section of the global, regional, and national impact of climate change on dryland agro-ecology. The authors detail not only constraints but also lay out the different pathways to achieve a more climate-resilient society.

The book emphasizes the importance of utilizing the best scientific findings including smart and precision agriculture, conservation agriculture, and innovation and new technology as tools for adaptation and mitigation.

Several chapters are devoted to the human dimensions and policy considerations with emphasis on enhancing coping and adaptive capacity. The book addresses events after COP27 including loss and damage, governance, and finance. The code of conduct of mankind in relation to nature should be addressed and emphasized globally with regards to the following:

1. promoting sustainable management of drylands as a solution to environmental and food security issues by adopting a holistic approach for sustainable development of these fragile eco-regions and translating science into action for greening global drylands;
2. undertaking dynamic assessment of the impact of climate change on agro-ecological zones to provide guidelines for sustainable management of global drylands; and
3. following up on declarations of COP27 and COP28, it is pertinent to address loss and damage, coping with uncertainties, enhancing adaptive capacity, governance, policies, and finance.

Main Features of the Book

A unique feature of the book is a holistic approach by authors from around the world to address the following aspects: innovations in agriculture; climate-smart agriculture/e-agriculture; agriculture 4.0; precision agriculture; conservation agriculture; carbon farming; utilization of genetic

resources (crop, livestock, fisheries) through new modes of genetic engineering/gene editing etc.; continuous assessment of the impact of climate change (CC) on agro-ecological zones; translating science into action; enhancing coping and adaptive capacity; and policy interventions.

It is important to strengthen cooperation with the local community including cooperative private sector research for development (R4D) continuum.

The book makes special reference to the dynamic change of the boundaries of agro-ecology impacted by climate change and the need for continuous assessment of the dynamic shift, which will require massive changes in cropping systems. There is a need for enhancing coping and adaptive capacity and policy aspects, including finance.

The book addresses the various convergence zones which were presented globally and during four webinars during the four pre-COP meetings organized by the International Dryland Development Commission (IDDC); Regional Action for Climate Change (RACC)/Science and Technology for Society (STS) forum; the Nizami Ganjavi International Center (NGIC); and the African League of Young Masters (ALYM), hosted by Ain Shams University (2022) and Alexandria University (2023) (IDDC, 2022, 2023) and STS/RACC in Kyoto, Japan (2022, 2023) (STS, 2023; Falk *et al.*, 2023, 2024). These meetings are projecting efforts needed to bridge the gap, especially after the COP27 breakthrough agreement on the new Loss and Damage Fund for vulnerable countries.

Main Elements in the Book's Chapters

Global chapters

Ch. 2: Navigation through Uncertainties

Part A: Regional Action on Climate Change

This part of the chapter states that our epoch of unprecedented human planetary impact demands an urgent collective response. Since the Anthropocene's conception in 2000, assessments confirm extensive disruption of climate, ecology, and environment, quantified by concepts like post-WWII's Great Acceleration. Crossing of planetary

boundaries nears catastrophe, defying one-size-fits-all solutions. At peak population, Wilson predicted that ecosystems surviving ecological bottlenecks will be irrevocably altered. Despite freshwater security linking diverse regions, integrated action lags. Recent African and G20 declarations (African Union, 2023; G20, 2023) signal a commitment to climate-smart agriculture, nature conservation, and biodiversity protection. However, averting biodiversity annihilation requires international campaigns leveraging gene banks and international and national organizations along with sufficient funding to introduce new genetic resources for the dynamic adaptation of agriculture. With crises converging, we do not have the luxury of time. Avoiding climate injustice demands equitable resilient responses. While daunting, humanity retains the urgency to act decisively, steering away from collapse towards sustainability. This pathway exists but it is narrowing. The stakes could not be higher.

Part B: Agro-ecosystems Affected by Dynamic Impact of Climate Change

The main elements impacting the vulnerability of agro-ecologies in the dry areas are elaborated with emphasis on the impact of water, biodiversity, land, livelihood of the population, and, consequently, the process of desertification. The danger of outmigration and its impact are discussed on global, regional, and national socio-political stability. The main outcomes of international agreements and conclusions in different COP meetings, including the Sendai framework for disaster risk reduction, the COP27 loss & damage fund and Justice are vividly discussed. It also elaborates on early-warning systems linked to the dynamic impact of climate change on agro-ecological zones. Adaptation as a priority for global climate action is one of the notable achievements of COP27. Aspects related to the adaptation were discussed in detail with emphasis on international cooperation, especially in relation to science and technology and the need to create a knowledge action network.

This part also addresses the shift in agro-ecological zones and the attendant changes in habitats which affect crops, livestock, and fisheries. Collaboration among global gene banks, both national and international (like CGIAR and Svalbard), is essential to ensure that collections give sufficient emphasis to stress-adapted genetic material that can contribute to adaptation to

climate change, and ensure that policies facilitate international exchange of the genetic resources needed to adapt farming systems to shifts in the distribution of climatic agro-ecological zones. It is critical to cope with uncertainty, recognizing that there will be shifting baselines as further assessment of climate change is done.

Funding is necessary to enhance gene bank passports with molecular characteristics and continue collection missions from dry areas, establish a global breeding program aimed at the development of new genetic make-up resistance to biotic and abiotic stressors, and develop an early-warning system for climate change impact on the shift of local agro-ecological zones. It is also important to support the transformation and modernization of agro-management techniques.

This chapter strongly recommends that a solid consortium be established which includes the national, regional, and international gene banks with international UN institutions, i.e. UNEP, FAO, IFAD, CGIAR, UNDP, IUCN, and Crop Diversity Trust, to activate the global gene bank partnership (GGP) platform and ensure investment for a research and information system which will serve the mission to address the shifting baseline in agro-ecology by providing suitable crops (animal, fisheries), and to continuously introduce new genetic resources for ever-shifting agro-ecology.

Emphasis is needed on human resources development and knowledge sharing at regional and international level. There is a need for establishment of the Loss and Damage Fund with clear indicators for its operation.

This chapter states that resilience knowledge must be seen as a universal asset. The gap between the 'haves' and the 'have-nots' must be bridged to ensure peace, stability, and prosperity. A shift in consciousness among the 'haves' and the 'have-nots' can lead to a new understanding of humanity's shared destiny.

Ch. 3: Carbon Farming in Global Drylands

The focus of this chapter is on sustainable management of global drylands (GDLs) for farming carbon (C), which implies growing C in land-based sinks to generate another income stream for farmers. Total C stock in GDLs comprises soil organic C (SOC) and soil inorganic C (SIC), and, in general, stock of SIC may be more than that of SOC.

GDLs play a significant role in regulating the global C cycle (GCC) and can be a sizeable sink for atmospheric CO₂ due to their large surface area and degraded soil. If decertified and degraded GDLs are restored, they have the potential to be a large sink for atmospheric CO₂. Yet scientific understanding of the controls of GDL-CO₂ exchange is poor. Thus, this chapter focuses on C farming as a strategy to address these issues.

Enhancing SOM content is a critical adaptation strategy in global drylands through improvement in water retention and nutrient cycling. Despite sparse vegetation but a large land area (> 40% of Earth's surface), GDLs have a large influence on global biogeochemical cycles and dominate the long-term trends in the GCC.

Some techniques discussed in this chapter to grow C stock in soil include the following:

1. Integration of livestock with crop and trees can increase diversification. Indeed, livestock play an important role in sustainable management of drylands at the farm, household and territorial levels with specific reference to food security, well-being, value-chain performance, food supply and maintenance of common grazing resources.
2. Afforestation of marginal drylands may strengthen several ecosystem services especially in temperate regions. However, there may be conflicts between additional forest area and water consumption with adverse effects on water yield.
3. Agroforestry systems are recommended for management of GDLs based on the production of indigenous crops. An agroforestry-based approach to mitigating climate change (and other issues including hunger, poverty, wildlife habitat etc.) is appropriate for sustainable management of GDLs.
4. Conservation agriculture (CA) in combination with integrated soil fertility management and complex crop rotations can be a conservation and soil-enhancing system for GDLs. Residue retention is a critical component of CA without which crop yield may decline and degrade soil functions. In addition to retention of crop residue mulch, effectiveness of CA also depends on adopting the strategy of integrated nutrient management (INM).
5. Soil-water conservation and management is the key to achieving food security and improving the livelihood of the large population of GDLs.

Thus, conserving water in the root zone, increasing water-use efficiency (WUE) and achieving more crops per drop of water are the major goals and principal challenges of agriculture in GDLs.

Sustained C sequestration in GDLs is a major challenge addressed in this chapter because of multiple resource limitations of resource-poor farmers. In addition to water, low nutrient availability may be one factor that inhibits C sequestration under dryland conditions. Judicious use of N fertilizer is critical to enhancing SOC stock but also moderating fluxes of CO₂, CH₄, and N₂O.

The chapter concludes with recommendations for a way forward to farming carbon in GDLs:

1. Protection of native biomes, restoration of degraded soils, and sustainable management of soils of GDLs offer an opportunity to reconcile the need to produce more food with the necessity of improving the environment.
2. Whereas the rate of soil C sequestration is low, GDLs cover a large area of 6–7 billion ha of land and can sequester a large amount of C as SOC and SIC.
3. Sequestration of SIC, through formation of secondary carbonates and leaching of bicarbonates, is an important component which needs to be addressed in the GDLs.
4. A system should be developed for payments to farmers for ecosystem services strengthened through sequestration of C in GDLs.

Ch. 4: Plant Genetic Resources for Adaptation to Climate Change in Drylands

This chapter, prepared under the lead authorship of Dr. R.S. Paroda, former DG of ICAR and Director of DARE, vividly explains the role of plant genetic resources (PGR) in the future and the adverse effects of climate change in the drylands of India. The chapter covers the conservation, utilization, and management strategies of PGR towards climate-resilient agriculture to ensure both agricultural sustainability and future food security. The authors deliberate that genetic resources could contribute greatly to cope with climate change, which is already affecting natural ecosystems and food production systems globally. The chapter focuses specifically on the effects of climate change on drylands in general and those of India in particular. The chapter

begins with an explanation of the impacts of climate change on agriculture, especially on agronomic yield under the conditions of rising temperatures and increase in frequency and intensity of droughts among increases in biotic stresses.

Significance of PGRs

With this background, the chapter focuses on the significance of PGRs under changing climate. In this context, therefore, the authors state that genetic diversity is a valuable resource for breeding programs, enabling the development of improved crop varieties with enhanced tolerance to abiotic stresses (e.g. drought, heat, salinity) and biotic stresses (e.g. pests, diseases). They further argue that PGRs also serve as a source of nutritionally rich and culturally important crops, promoting dietary diversity and food sovereignty, which is specifically relevant to countries where large populations are prone to hidden hunger and malnutrition.

With the goal of adaptation and mitigation of climate change in dryland agriculture, the authors explain that traits that would be needed would include short life cycles, deep root systems, waxy leaves, water storage capabilities in roots and trunks, dormancy during droughts, and tolerance to high temperatures. Among the three main components of climate change, temperature has large effects, both in terms of lethality at high and low temperatures and in affecting both phenology and distribution of crops, and PGRs can play a significant role in addressing these issues.

Case Study on PGR Diversity in Indian Perspective

The authors appropriately elaborate on the unique success of Indian agriculture in achieving the Green, White, Yellow, and Blue Revolutions. Yet, they also highlight the impact on degradation of natural resources which are particularly severe in the Green Revolution corridors of India. Therefore, they focus on:

1. Dryland agriculture in India

Drylands occupy 80 mha of cropland where are also located 50% of the total rural workforce and 60% of India's livestock. In addition to horticultural crops, the forage genetic resources (e.g. lucerne, cowpea, range grasses, legumes, trees, and shrubs) can play a significant role in improving adaptability to harsh environmental conditions.

2. PGR diversity in dryland

The chapter explains the rich crop diversity in the Indian arid zone in terms of species, genotypes, and ecotypes, etc. The authors highlight that agrobiodiversity contributes to resilience through the protection and restoration of ecosystems, the sustainable use of soil and water resources, agroforestry, diversification of farming systems, various adjustments in cultivation practices and the use of stress-tolerant crops and crop improvement.

3. PGR management and climate-resilient agriculture

The authors propose the development of a Red Data Book devoted to arid region biodiversity and suggest that incentives and rewards be provided to farmers who actively conserve the agrobiodiversity. Germplasm conservation can be either *in situ* protectionism or *ex situ* conservationism. Indian gene bank conserves germplasm *ex situ*. Authors also propose an integrated or *trans situ* approach based on ecology, biology, diversity and utility of the targeted plants. The chapter also describes the importance of traditional knowledge and community involvement and provides specific examples from Rajasthan, Haryana, and Punjab, and that followed by the Bishnoi community.

4. Utilization of PGR

Among examples of utilization of PGR, the authors describe options of:

1. breeding for climate resilience;
2. use of biotechnology and molecular breeding;
3. identification of desirable traits and reviewing mitigation strategies;
4. strategies for climate-smart agriculture;
5. conservation agriculture;
6. crop diversification; and
7. numerous other approaches for reshaping and evolving production systems to cope with changing climate.

5. Global forums and international treaties

Finally, the chapter describes examples of international treaties such as those of the UNFCCC, UNCCD, CBD and the Commission on Genetic Resources for Food and Agriculture (CGRFA) under the auspices of FAO, along with an International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). This section also lists many global

online portals which serve as a source CWR inventories.

The chapter concludes with a set of 14 specific recommendations to cope with problems in agriculture arising due to climate change in dryland ecosystems.

Ch. 5: Agro-management Techniques and Precision Agriculture/Agriculture 4.0 in Arid Lands

This chapter on precision agriculture (PA) or e-agriculture is authored by a team of researchers from ICARDA, from Salman University in Sinai, and Ain Shams University. PA, or site-specific crop management, is defined as agriculture that increases the number of (correct) decisions per unit of area of land per unit time with associated net benefits. It is an approach to agriculture that uses data sensors, connected devices, remote controls, and other advanced technologies to give farmers more control over the field. More specifically, PA links agricultural management systems with modern technology that contributes to improving and sustaining the use of natural resources, especially soil and water, increasing the quantity of production and improving its quality.

The chapter outlines specific soil functions which can be enhanced by the use of PA including remote-sensing technology, GIS, data management and the Internet of Things (IoT) for an accurate measurement of differences in the field at the right time, allowing the right decision to be made at the right time and maximizing the return from available natural resources. Authors vividly explain that PA is a management method aimed at reaching the highest production using the lowest inputs while maintaining the integrity of the surrounding environment and managing fields based on soil types, soil units in different areas, and dynamic soil quality indicators.

Some applications of PA in the context of arid agriculture lands discussed in the chapter include the following:

1. Applications of IoT

The chapter explains that PA is an approach used in farm management and crop control through information and communication technology, remote sensors, remote control systems, and autonomous machines to obtain

accurate data and invest these data in directing agriculture accurately towards greater production at a lower cost, and the production of high-quality crops. Other important applications discussed in the chapter include the use of drones to monitor and evaluate crops, photograph, and map agricultural lands, measure air components, spray crops with pesticides quickly and safely, send data instantly to software that analyzes them and instructs farmers to implement the best procedures.

2. Integration of PA techniques to achieve agricultural sustainability

In this section, authors list examples of some sensors used in PA. Prominent among these are:

1. sensors capable of aerial photography such as cameras carried on drones;
2. soil quality sensors and the condition of the elements in the plant;
3. electrochemical sensors; and
4. smart temperature sensors.

3. Revitalizing dryland rainfed systems under changing climate

The chapter describes the use of PA systems in revitalizing the dryland rainfed systems with specific focus on water resources as a critical factor for all production systems in relation to agriculture in Egypt and elsewhere in global drylands. The authors emphasize that by 2025, as many as 29 countries in the world are expected to experience water scarcity, including 18 countries in the Middle East and northern Africa classified as water-scarce. Therefore, many countries have recognized the urgent need to secure, rationalize, and utilize new irrigation technologies and techniques such as SMART irrigation management to sustain minimum resources base, as well as modify the traditional irrigation systems. The low annual crop yields increase in many Arab regions (1.5% per year) and can be improved by adopting PA systems for sustainable management of water resources. The authors argue that potential loss in rainfed areas in some MENA countries due to climate change may lead to a 20% reduction in annual precipitation.

However, there is a considerable potential for vertical productivity increases in most of the crops. Rainfed grain yields, on average, around

1.0 t/ha compared with about 3.0 t/ha in irrigated agriculture. Thus, the authors argue that there is a large untapped potential in rainfed agriculture in the drylands which can be realized by the adoption of PA.

Constraints to improved dryland farming and the need for change of strategies

The chapter outlines three specific constraints to improving dryland farming. These include:

1. climate constraints due to temporal and special variability in rainfall;
2. soil constraints due to poor soil water infiltration and storage capacity, poor soil fertility, and nutrient deficiency; and
3. adoption constraints due to a lack of knowledge and low financial capacity.

The authors explain that these constraints can be addressed by adopting strategies such as: enhancing water availability, increasing crop water uptake, improving rainwater productivity, and adopting climate-smart agriculture under rainfed conditions.

Key practices and approaches

Examples of key practices outlined in the chapter include supplemental irrigation, rainwater harvesting, agronomic and conservation practices, and adoption of digital rainfed agriculture. However, specific focus is given to PA and smart irrigation systems along with explanation of devices and tools for operating smart on-farm irrigation systems. The authors also list devices required for the automatic operation of smart irrigation systems including soil moisture sensors along with measuring and control devices.

Energy in PA system, agricultural mechanization, and post-harvest services

In these sections the authors explain renewable energy such as solar, wind, and green hydrogen energies. The section is devoted to agricultural mechanization with a focus on modern agricultural power and machinery.

The chapter concludes by stating that on-farm irrigation systems and their management are one of the most important agricultural sectors in applying the concept of precision and digital sustainable agriculture. Water saving, a critical factor in the success of farming in dryland, can be achieved by precisely computing the amount of water that plants require and applying it at the right time and by the right

methods, which enhance use efficiency of the most precious but finite resource.

Ch. 6: Impact of Climate Change on Inland and Ocean Fisheries and Aquaculture

This chapter provides an in-depth analysis of the multifaceted effects of climate change on these critical sectors. It begins by emphasizing the global significance of both inland and ocean fisheries and aquaculture, highlighting their roles in providing nutrition, employment, and economic benefits worldwide. The chapter then delves into the historical evolution of these sectors, noting their growth and increasing contribution to global fishing activities.

It also explores various adaptation strategies to mitigate the impacts of climate change on fisheries and aquaculture. These include adopting new technologies, modifying fishing practices, and implementing policy changes to support sustainable fishing and aquaculture practices. Emphasizing the need for localized solutions, the chapter suggests integrating traditional knowledge with scientific research to develop effective adaptation strategies. It calls for collaborative efforts between governments, research institutions, and communities to develop and implement policies that ensure the long-term sustainability of these sectors in the face of climate change.

It explains how changing climatic conditions are altering fish habitats, thus leading to shifts in fish stock abundance and distribution. This phenomenon is particularly evident in both inland and ocean fisheries, where species are migrating to cooler waters, disrupting traditional fishing patterns and practices. The chapter also discusses the increased frequency and intensity of extreme weather events like storms and heatwaves, which have direct and indirect impacts on fisheries and aquaculture operations. These changes pose significant challenges to the sustainability of these sectors and the livelihoods they support.

Another critical aspect covered in the chapter is the role of genomics in managing and conserving the genetic resources of fish species. The advancement in genomic technologies offers potential solutions to the challenges posed by climate change. By enhancing the understanding of the genetic make-up of fish species, these technologies aid in developing more resilient fish

breeds and conservation strategies. The chapter explains how genomics is being integrated into breeding programs to develop species that can better withstand changing environmental conditions.

In addition, the chapter also stresses current operations, and emphasizes that the emerging and pending stresses of climate change have pushed better-endowed fishing and farming enterprises, research and development institutes and entrepreneurs to strive for more cutting-edge technological fixes.

In aquaculture, the technological fixes address current bottlenecks such as the supply and cost of feeds in aquaculture and/or the desire for much greater control over the aquaculture process. In marine fisheries, fisheries management and fish stock assessment technologies are of paramount importance.

The chapter also addresses the unique challenges faced by the impact of climate change on dry areas in developing countries. The impacts of climate change are often more acute, with increased vulnerability due to limited resources and adaptive capacities. The chapter discusses how changes in rainfall patterns and increased temperatures are affecting inland fisheries, especially in arid and semi-arid regions. This situation exacerbates the challenges for communities that rely heavily on these resources for food and livelihoods. In developing countries, the reliance on fisheries and aquaculture is often a critical component of food security and economic stability. The chapter highlights the need for targeted strategies in these areas, focusing on sustainable practices, capacity building and the development of climate-resilient species through advanced genomics and breeding programs. It emphasizes the importance of international co-operation and support to help these regions adapt to the changing climate, ensuring the sustainability and resilience of fisheries and aquaculture in some of the world's most vulnerable areas.

Ch. 7: Impact of Climate Change on Livestock in Drylands

This chapter offers a comprehensive analysis of how changing climatic conditions affect livestock and the adverse interrelationship between them. It begins by highlighting the critical role

of livestock as a vital asset in dryland regions, both for their economic value and cultural importance. The chapter delves into the direct impacts of climate change, such as temperature fluctuations, water scarcity, and prevalence of diseases, along with indirect consequences such as changes in feed crop yields and quality.

A significant portion of the chapter is dedicated to discussing the contribution to greenhouse gas (GHG) emissions, drawing attention to the need for strategies to mitigate these effects. The chapter also emphasizes the adaptive capabilities of different livestock species to environmental stressors, underscoring the importance of genetic diversity and the development of heat-tolerant animal breeds.

Mitigation strategies proposed in this chapter include improving animal management practices, enhancing nutrition, and advancing selective breeding and genetic engineering to develop resilient livestock breeds. The authors argue for an accurate measurement of heat stress in animals and the development of early-warning systems as essential tools in managing climate-induced challenges.

The chapter concludes by stressing the urgency of addressing the interplay between climate change and livestock farming. It calls for more research, policy interventions, and community engagement to ensure the sustainable management of livestock in dryland regions, highlighting the need for coordinated efforts in this direction. The holistic approach presented in the chapter underscores the complexity and interdependence of environmental, economic, and social factors in managing livestock under the looming threat of climate change.

Regional chapters

Ch. 8: Sub-Saharan Africa

This chapter is contributed by competent scientists experienced in a wide range of issues. Urgency to address Africa's food and climate security are highlighted by the fact that the continent is prone to extreme weather events: heatwaves and wildfires in the north; rising temperatures, droughts and destructive floods in western and central regions; and cyclones and catastrophic flooding in the southern regions. Thus, the

continent continues to suffer from vulnerability of hunger and malnutrition.

The authors state that many ecoregions of Africa are fragile and prone to drastic effects. For example, drylands cover 19.6 million km² and are home to 40% of Africa's population or 525 million people, and are growing at 3.0% per year. Further, the regional warming in drylands may be up to twice the global increase in temperature. The problem of food insecurity is aggravated by the prevalence of drought and by the war in eastern Europe. Therefore, the authors highlight the need for African countries to strengthen social safety nets, invest more in research and development, avoid trade restrictions, and implement initiatives such as the Comprehensive Africa Agriculture Development Program (CAADP).

The chapter examines emerging and potential impacts on food security on the continent, considering each dimension of food security: availability, access, utilization, and food system stability. Climate-related food insecurity challenges in two especially threatened areas are considered in detail: the Sahel and the Horn of Africa. Specific focus is given to trends and projects of climate change, droughts, floods, cyclones, storms, heatwaves and desertification. The authors discuss the effects of these climatic factors on all interrelated aspects affecting food security: namely food availability, food access and food utilization.

The chapter also focuses on the stability of Africa's food systems in the context of climate and economic shocks. The authors highlight that hardly 1% of arable land in Africa is equipped for irrigation. Food insecurity is also aggravated by food loss because of poor storage capacity of households and warehouses resulting in significant food loss, averaging 9% each year in Africa. Food insecurity in Africa is also aggravated by increases in food prices, decrease in family income and poor distribution to the affected areas.

The authors highlight the food insecurity hotspots which comprised 16 countries during 2022, out of the world's total of 24 countries. These food insecurity hotspots are attributed to chronic poverty and vulnerability, low and erratic rainfall, uneven access to feed in depleted rangelands, flooding, pest attacks, domestic food price inflation, and conflict and displacements.

Because of these factors, food insecurity in the Sahel region has increased by 50% since 2021. Consequently, 18 million people are affected in the Sahel and 24 million in the Horn of Africa.

The chapter also focuses on possible solutions to this problem that has affected Africa since the 1960s. The authors emphasize that Africans are responsible for their own food security and need to carry out the necessary reforms and investments to assure food security through development and implementation of policies and investments in African countries to help translate science into action. Priority actions with regards to investment highlighted in the chapter include the following:

- 1.** enhance the financial, technical, and organizational capacities of national agricultural research and extension systems;
- 2.** strengthen regional and international agricultural research and development organizations and consortiums (i.e. CGIAR);
- 3.** strengthen the structure and functioning of national and regional farmer and trader organizations; and
- 4.** expand agricultural market and value-chain infrastructure and services, prioritizing climate-smart common assets for value addition.

The chapter emphasizes the importance of investment in water resources and environment, with a focus on reducing the emission of greenhouse gases by restoring degraded and decertified ecosystems and on cross-sectoral actions (e.g. energy).

Among the principal recommendations highlighted by the authors are:

- 1.** progress towards a pan-African climate adaptation and food security initiative;
- 2.** establishment of the African Council of Agricultural Research and the Forum for Agricultural Research in Africa (FARA), which will guide research and provide funding support;
- 3.** funding support from the IMF and other international organizations at \$50 billion per annum for adaptation, and another \$190 billion per annum for mitigation efforts on global warming in Africa;
- 4.** the creation of a Green Bank at about \$2 trillion per annum; and
- 5.** translating science into action, urgently needed for Africa through creation of the Technologies

for African Agriculture Transformation (TAAT) program to replicate the success stories such as cassava in Nigeria, maize in Kenya, rice in Sierra Leone, and sorghum in Mali, among others.

The chapter focuses on identification of pathways to achieve food security in Africa and concludes by stating that Africa is the biggest victim of climate change caused mostly by developed economies. The authors emphasize that more investment is needed in agriculture, water, and environment, along with those in agricultural research and education. The importance of continental free trade is highlighted as an opportunity to increase regional trade in food and agricultural products. Two options recommended are:

1. creating a Green Bank to finance private sector green projects; and
2. debt for climate swaps to provide African governments with adequate fiscal space to finance climate investments.

Ch. 9: Case Studies in America on Carbon Management and Sequestration in Agriculture

This chapter focuses on case studies from Latin America. The authors have long experiences in Brazil, Uruguay, and other countries. It focuses on biomass C-based practices as the primary pathway to develop resilient, regenerative, profitable, and environmentally friendly production systems. It includes case studies on C balance with biomass-C inputs across production systems in South and North America. It also highlights the role of the Inter-American Institute for Cooperation on Agriculture (IICA), which plays a strategic role by partnering with national scientific and technological institutions, and promotes Living Soils of the Americas project, implemented in cooperation with the CFAES Rattan Lal Center for Carbon Management and Sequestration.

Three case studies presented in the chapter are:

1. biomass-C input interaction and C balance across production systems under no-till (NT) in Brazil;
2. diverse crop and soil management practices from the western USA; and
3. evidence from different crop rotations in a long-term experiment in Uruguay.

Case study from Brazil

This case study focuses on the use of no-till in Brazil for about 50 years. The no-till system (NTS) was used in Paraná state, followed by Rio Grande do Sul (southern region). These were the ecoregions where the NTS was initially adopted to control soil erosion. In the long-term, the NTS proved to be one of the most important technologies that supported upscaling of Brazilian agriculture. Brazil currently has 36.8 million ha under NTS, but only 10–15% have successfully adopted NTS based on the three pillars (absence of soil disturbance, permanent soil cover, and diverse crop systems).

The data on SOC sequestration rates for tropical (-0.03 – $2.15 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) and subtropical (-0.07 – $1.4 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) regions of Brazil vary widely because of differences in the amount of biomass-C input and the agronomic potential of agro-ecosystems. Large variability in SOC sequestration rates may be attributed to a high diversity of cropping systems, the amount and frequency of biomass-C input, and the difference in inherent soil properties. The authors argue that making Brazilian agriculture emission-negative can be achieved by maximizing the soil C sink by increasing the CO_2 fixed by crops during photosynthesis and its accumulation in soil profile upon land application of biomass-C.

The authors propose that the key component to reach a positive C balance in farming production systems is to manage biomass-C input in association with NTS envisaging to accumulate and stabilize C by three mechanisms:

1. stimulate formation of macro-aggregation through continuous soil cover;
2. control the rate of SOC oxidation; and
3. ensure stabilization of C in intra-aggregate and the associated organic C.

Case study in the western USA

This study presents the evidence from studies comparing tillage systems, crop rotation, cover cropping, and perennial cropping systems in the semi-arid eastern New Mexico and other studies from across the western USA. The study highlights the importance of:

1. reducing soil disturbance;
2. intensifying and diversifying cropping systems;
3. using perennial cropping systems and grassland restoration; and

4. exploring dual opportunities of carbon and water management.

The authors of this study argue that improved farming practices such as cropping system intensification and diversification, cover cropping, crop rotation, mixed-cropping, and conservation tillage can improve water-use efficiency and enhance biomass-C input for enhancing SOC sequestration and soil-water conservation benefits. Furthermore, integrating reduced and no-till with cropping systems intensification, diversification, and enhanced residue inputs could increase SOC in arid and semi-arid regions and also improve soil-water conservation.

Case study from long-term experiments in Uruguay

This case study is focused on different crop or crop-pasture rotations studied for 60 years in the oldest long-term experiment in Uruguay, initiated in 1963 and located at the INIA Experimental Station 'La Estanzuela' (34°20'S, 57°41'W). The data from long-term study showed the following:

1. the SOC decreased nearly constantly in continuous cropping without N and P fertilization;
2. SOC declined at a lesser rate and became stable at SOC level of 1.5% under continuous cropping but with N and P fertilization;
3. crop-pasture rotation with red clover (*Trifolium pratense*) resulted in a relatively steady SOC content over the long term compared to the starting condition;
4. with less intensive crop-pasture rotations that had 50% crops and 50% pastures, SOC slightly increased over the long term; and
5. SOC content increased steadily in a crop-pasture rotation that presented only two years of crops rotating with two types of pastures, one lasting one year and the other lasting three years. A pattern of decrease in SOC during cropping phases and increase during pastures was recognized for several crop-pasture rotations within the rotation cycles of this long-term experiment.

Ch. 10: Central and West Asia and North Africa (CWANA)

The region is experiencing an increase in the events of climate change resulting in droughts, floods, and high temperatures compounding events with significant consequences for society

and the environment. To overcome the negative effects of climate change, the International Centre for Agricultural Research in Dry Areas (ICARDA), alongside its national and international partners and donors, promotes diversified cropping systems and delivers its solutions as integrated packages including innovative technologies, capacity-building programs, instruments for better market access, and the current best agronomic approaches. These include sustainable, water-smart irrigation, cultivation of drought-tolerant crop varieties, water management approaches such as rainwater harvesting and deficit irrigation, precision farming technologies, and low-water-footprint cropping systems, raised-bed technology, and others.

One of the important contributions of ICARDA has been the collection of germplasm, its characterization and distribution to all member states of the region.

ICARDA in collaboration with the Pavlov Institute in Russia and GRDC Australia has developed FIGS (The focused identification of the germplasm strategy), which is a trait-based approach and assists gene bank managers in identifying desired gene material with high probability of having the sought-after trait. FIGS is based on the premise that the environment strongly influences natural selection and, consequently, the geographical distribution of organisms. FIGS has been successfully used to identify sources of resistance for several useful traits for breeding globally such as Sunn pest in wheat in Syria, Russian wheat aphid in bread wheat, abiotic stresses, such as drought adaptation in *Vicia faba* L., resistance to stem rust in bread and durum wheat, and stem rust and stripe rust in accessions of wheat landraces.

Heat- and drought-resistant variety development by ICARDA

With this information, together with the new genotyping technologies, breeders have been able to identify the genetic mechanisms behind superior tolerance to heat and drought. Cropping season 2021–2022 was one of the harshest of the last 50 years in Morocco.

It is worth mentioning that, until now, ICARDA has released more than 880 new varieties for cultivation – and generated benefits worth US\$850 million every year. Technology 'packages' have been developed – crop management, irrigation, pest control – to maximize yields from

the new varieties. In the last five years, more than 120 cereal and legume varieties of ICARDA origin have been released by the national programs in more than 20 countries.

In addition to providing various genotypes, ICARDA is actively involved in water conservation technologies and different agronomic practices for mitigating climate change effects. This has been demonstrated through different case studies of intervention made in different regions/countries.

The chapter concludes that restoration of soil health should be based on the following:

1. increasing the biomass-C input according to the three pillars that support conservation agriculture, adding the amount at the rate above that of the dynamic equilibrium, guaranteeing a controlled soil C oxidation rate, and promoting the continuous C and N flow to reorganize the aggregates and the new structure;
2. stimulating macro-aggregation and enhancing C protection within intra-aggregates and stabilizing it over time and restoring soil functionality by improving soil's chemical, physical and biological attributes; and
3. managing the rate of input of biomass-C as a key strategy to decrease C turnover time and leading to the restoration of natural capital and ecosystem services to society.

National chapters

Ch. 11: Innovations, Strategies, and Policies for Building Resilience of India's Dryland Farming to Climate Change

This chapter is contributed by authors from ICRI-SAT, ICAR-NAARM and ICAR Natural Resources Management Division, and is aimed at building resilience of India's dryland farming to climate change. The chapter outlines India's new programs and innovative strategies for climate proofing of agriculture through National Action Plan on Climate Change (NAPCC). It deliberates major initiatives such as National Mission on Sustainable Agriculture (NMSA), National Innovations on Climate Resilient Agriculture (NICRA) and international collaborative programs, i.e. conservation agriculture (CA), landscape approach, etc.

The chapter focuses on climate risks in Indian agriculture and then outlines strategies to

address these risks. Important climate risks are erratic monsoons, extreme weather events, heatwaves and extreme temperatures, water scarcity and depletion of groundwater resources, pests and diseases, shifts in crop suitability zones, and livestock vulnerability and adaptation challenges. Thereafter, the authors describe the need for climate-resilient agriculture (CRA), which encompasses a combination of sustainable and regenerative agricultural techniques such as conservation agriculture, use of climate-resilient crop varieties, agroforestry, measures to manage water resources effectively during droughts and floods, crop rotation and diversification, and precision farming.

National initiatives on climate proofing in Indian agriculture

The chapter outlines various initiatives undertaken in India such as the National Action Plan on Climate Change (NAPCC) in 2008. Other initiatives discussed include:

1. National Innovations in Climate Resilient Agriculture (NICRA) in February 2011. It is operated with the objectives to:
 - (i) undertake strategic and applied research on climate change adaptation and mitigation;
 - (ii) validate, demonstrate, and assess the impact of climate-resilient technologies on farmers' fields; and
 - (iii) strengthen the capacity of scientists, farmers, and other stakeholders on climate-resilient agriculture.
2. National Mission for Sustainable Agriculture (NMSA), which focuses on promoting climate-resilient agriculture through the adoption of climate-resilient practices, sustainable water management, and integrated farming systems.
3. Green India Mission (GIM) with the objective to safeguard the biological resources of India and associated livelihoods against the peril of adverse climate change and to recognize the vital impact of forestry on ecological sustainability, biodiversity conservation and food-, water- and livelihood-security. Climate finance under which the [National Adaptation Fund for Climate Change \(NAFCC\)](#) was established in 2015 to meet the cost of adaptation to climate change for the state and union territories of India that are particularly vulnerable to the adverse effects of climate change. Also discussed are the National

Food Security Mission, the Mission for the Integrated Development of Horticulture, the National Bamboo Mission, and the National Livestock Mission.

The authors discuss international initiatives and programs on CRA in India including the CGIAR Research Program on Climate Change, the Climate Change Agriculture and Food Security (CCAFS), Sustainable and Resilient Farming Systems Intensification (SRFSI) in the eastern Gangetic Plains, landscape approach for scaling climate-resilient, regenerative and carbon-neutral agricultural systems, and the conservation agriculture (CA) initiative.

The chapter focuses on CA and states that science-based CA management has the potential to produce more food (10–15%) from less water (20–75%) and energy (20–45%) while increasing farmers' income (25–50%) in an environmentally responsible manner through lowering the C footprint by 25–30%. Thus, the chapter includes a table of references citing evidence of climate-resilient agriculture practices in different regions of India for site-specific farming systems. The authors outline some policy needs on climate proofing both at national and state levels.

Community of practitioners (CoPs) and networks on climate proofing in India

The chapter outlines several communities of practitioners (CoPs) and networks in India focusing on climate proofing and addressing climate change challenges. These initiatives are aimed to foster collaboration and knowledge sharing among various stakeholders, including government agencies, non-governmental organizations (NGOs), academic institutions, and local communities. The chapter also lists some examples of potential CoPs and networks on climate proofing in India.

Potential opportunities for scaling of climate-resilient agriculture

The authors claim that CRA is the most cost-effective and scalable solution. It offsets or reduces the net CO₂ emissions and is the key to mitigating the major factor of global warming and climate change. The chapter outlines some potential opportunities for scaling climate-resilient agriculture such as the need for policy and financial support, knowledge sharing and capacity development, climate-resilient technologies, climate finance mechanisms, carbon credits, public-private

partnerships, farmer cooperative networks, climate-resilient certification labelling, etc.

The concluding section outlines some key steps to move forward with CRA in India. Important among these are:

1. scaling up successful initiatives;
2. enhancing climate research and data;
3. mainstreaming climate into development plans;
4. empowering local communities;
5. private sector engagement;
6. capacity building and training;
7. incentivizing climate-resilient agriculture through carbon credits;
8. innovative financing mechanisms;
9. public awareness behavioral change;
10. collaboration and international cooperation; and
11. review and adaptation.

The chapter concludes with the statement that addressing climate change is a complex and multifaceted challenge and building resilience to climate change is a long-term endeavor that requires sustained commitment from all stakeholders.

Ch. 12: Climate Change and Sustainable Agro-ecology in China's Dryland: A Case Study

This chapter reviews the problems and challenges in climate-smart agricultural practices of China's dryland farming. The chapter is based on the premise that application of CSA management practices in China's dryland can increase the amount of soil organic carbon (SOC) and maintain or increase crop yield, with the hope of also reducing the emission of GHGs. Of the total amount of arable land area in China, at 130–171.3 million ha, approximately 50% is drylands. The focus of this chapter is adoption and upscaling of CSA technologies in China's drylands. Important among these technologies are improved systems of nutrient management and the use of water-saving agricultural technology, conservation agriculture, crop diversification, plastic film management, and integrated management practices that facilitate soil fertility. Based on the review of the literature, the authors emphasize that conservation and organic agriculture can improve soil nutrients, reduce

environmental costs, and maintain soil health, but the benefits for yields are controversial. While irrigation can reduce GHG emissions and improve crop productivity in dryland agriculture, the site-specific effects depend on irrigation methods: flooding and furrow or sprinkler irrigation.

The authors emphasize that most studies on CSA management practices focus primarily on a single technology or the entire farmland system, but few studies have systematically reviewed the progress and challenges of CSA in drylands. Therefore, this chapter is an attempt to provide a deeper understanding of the methods of dryland farm management in China and proposes new strategies to advance CSA. This review is specifically focused on the following CSA practices:

1. Conservation tillage

It is estimated that conservation tillage is practiced on some 8.6 mha of cropland in China. However, the responses of crop yields to conservation tillage are controversial and debatable in China. Therefore, the authors emphasize the need for appropriate strategies that alleviate yield limitations and harness the benefits of conservation tillage to improve production. The need for investigation of the mechanisms of SOC sequestration is highlighted. Research is also needed on environmental factors (e.g. temperature, moisture, and pH) and soil C and N components as the key factors that affect the emissions of N₂O from soil managed by conservation tillage. With proper management package, conservation tillage could be a preferred 'climate-resilient' technology to lower the carbon footprint and enhance the ecosystem services of climate regulation for the winter wheat-summer maize system in the north China plain.

2. Optimizing chemical fertilizer input

Integrated nutrient management is a strategy to maintain optimal ecosystem productivity and sustainability for fertilizer use in dryland systems of China. It involves combined use of organic and mineral fertilizers, combined with patterns of crop nutrient demands to improve the nutrient use efficiency. A judicious combination of organic and synthetic nitrogen fertilizers offers a nutrient-rich source that complements intermediate nutrients and micronutrients. A 26-year study showed that

combined application of organic and mineral fertilizers increased the total concentration of organic carbon, organic carbon stocks, and labile fractions of organic C. However, applications of inorganic fertilizers often produce contradictory effects on the concentrations of SOC and its fractions.

3. Water-saving agriculture

Some options to save water discussed in the chapter for semi-arid regions of China include conservation tillage, limited irrigation, drought-resistant chemical control, and the use of water-saving varieties over and above the use of drip irrigation or micro-irrigation. In the semi-arid areas of the Loess Plateau, the yield-enhancing effects of plastic film mulching are reported in this chapter to be somewhat limited and even leading to reduced yields and production. Use of full plastic film mulching may negatively affect the storage of soil carbon and control of GHG emissions. Yet, the application of highly absorbent polymers can promote wheat growth, improve root vigor, increase wheat dry-matter weight and tiller number, enhance soil physicochemical properties and water-use efficiency, and increase agronomic yield. Site-specific effects of these water-saving options, i.e. drip- and micro-irrigation are discussed.

4. Biochar

Despite numerous reports on the use of biochar, the authors also highlight debate and disagreement in the results. The chapter elaborates on the available data and states that the efficacy of biochar as a soil enrichment is based on appropriate biochar technology. In other words, field management practices must fully account for soil type, basic fertility, and the type and amount of biochar used as a feedstock. The chapter discusses that biochar may be more effective in fertilizing degraded land with poor soil fertility than on a fertile soil with high productivity. Also discussed are saline soils and those with other constraints to crop production.

5. Plastic film mulch

Because of its widespread use in China, pros and cons of plastic film mulching are elaborated in this chapter, especially with regard to net radiation input in arid regions where the warming effect follows a U-shaped trend throughout the crop reproductive period. While plastic film mulching can increase the

soil-water content of the cultivated layer by 1–4%, in years with less rainfall, plastic film mulching can reduce the subsoil water content, with no difference in soil-water storage between 0 m and 2 m depth. Nonetheless, the authors discuss that plastic mulching has an impact on early sprouting, seedling emergence, and the growth of stems with leaves, specifically the root system, and on the effectiveness of soil nutrients uptake by crops. They highlight that extended and irrational use of mulch over the longer term can nullify the initial gains in yield by reductions in yield over the longer period when the residues would persist for a long time and aggravate plastic pollution.

The chapter concludes with a detailed case study from north-east China. The case study is based on long-term research involving technologies such as intercropping, dryland autumn mulching, and monopoly film sowing over the straw to improve the efficiency of water and fertilizer use in dryland crops. It highlights challenges and opportunities for future development in the region, which is the breadbasket of China. The chapter concludes that CSA management faces significant challenges in balancing the relationship between organic carbon sequestration, food security, and GHG emissions under site-specific conditions. Thus, identifying and prioritizing appropriate CSA practices are necessary to help establish sustainable agricultural production systems in arid regions.

Ch. 13: Dryland Agriculture in Pakistan under Changing Climate: A Case Study

Pakistan has a predominantly arid to semi-arid climate, where 5 mha of the cultivable land is rainfed. Droughts have severe repercussions in the country, including food shortage, animal losses, crop failure, and water scarcity. This situation makes Pakistan one of the most vulnerable countries to climate change. In order to overcome these conditions, Pakistan has adopted various mitigation strategies for conserving water through better water reservoir management, lining irrigation channels. In addition, high-efficiency irrigation systems (HEIS) are being adopted to conserve water.

Adaptation measures for agriculture

Climate change adaptation strategies for the agricultural sector are crucial. Adaptation measures

for agriculture can help farmers cope with the challenges of climate change and build resilience in their farming systems. However, the success of these measures depends on a range of factors, including access to finance, technology, supportive policy frameworks, and effective partnerships between farmers, governments, and other stakeholders.

Here are some examples of adaptation measures that can be implemented in agriculture:

- i. **Crop diversification.** Farmers can diversify their crops by growing a variety of crops that are better suited to changing climate conditions, crop rotation, and intercropping.
- ii. **Water management.** Using efficient irrigation systems, rainwater harvesting, and agriculture practices for water conservation can help to increase water-use efficiency, reduce soil erosion because of runoff, and increase soil moisture to improve soil health.
- iii. **Improved soil health.** Improving soil health with practices like conservation agriculture, cover cropping, and agroforestry can help to enhance soil organic matter, lessen soil erosion, and promote soil fertility, thus improving crop productivity and resilience.
- iv. **Use of climate-smart technologies.** Farmers can use climate-smart technologies such as solar-powered irrigation systems, improved seeds, and precision farming technologies to increase productivity and reduce vulnerability to climate impacts.
- v. **Early warning systems.** Implementing early-warning systems for extreme weather events, pests, and diseases can help farmers to take appropriate measures to reduce damage to their crops and lessen their susceptibility to the effects of the climate.
- vi. **Improved seeds and technologies.** Selecting drought-tolerant crops together with modern agriculture practices such as precision farming (e.g. drip-irrigation and mechanization) can significantly increase dryland productivity.
- vii. **Training and education.** Providing farmers and stakeholders with training and education on climate-smart agriculture practices can help them to adopt water-efficient irrigation, crop management, and soil conservation, which are critical to improving dryland farming.

The impacts of climate change, such as droughts, floods, and changing weather, are already being felt by farmers nationwide, particularly

in the dryland regions. To address these challenges and build more resilient and sustainable farming systems, there is a need to adapt scientific interventions that consider the local context and the needs of farmers. Adaptation measures such as developing climate-change-resilient genotypes, crop diversification, conservation agriculture, and water management can help farmers cope with the impacts of climate change and improve their livelihoods. Though the scientific community is playing its role, more focused research needs to be initiated. Policy decisions and legislation for adopting new technologies must be sensitized and revised. Likewise, re-zoning is also equally important to uplift agriculture in the drylands. Certain initiatives taken by the government are encouraging water conservation and sustainable agriculture practices, thus helping to mitigate these challenges. Hence, there is a dire need to devise short-, medium-, and long-term policies to uplift dryland agriculture in the country.

Ch. 14: Resilience and Adaptation of Egyptian Agriculture

This chapter provides a comprehensive analysis of the challenges faced by Egyptian agriculture in the context of climate change. The primary focus is on the impacts of limited resources, sea-level rise, dwindling water supplies, and population growth. The chapter underscores the need for a significant transformation in agricultural practices to combat the effects of climate change. It highlights the 'Sustainable Agriculture Development Strategy towards 2030', which incorporates advances in science and technology, including smart agriculture, and emphasizes the importance of human resources development, institutional support, policies, and legislation.

The chapter provides a detailed examination of the vulnerabilities of Egyptian agriculture to climate change, including issues related to sea-level rise, soil salinity, and desertification. It emphasizes the serious implications of these challenges for the economy, food security, outmigration patterns, public health, and livelihoods. The chapter also addresses the vulnerability of Egypt to rising sea levels, particularly in the Nile Delta, Alexandria, and North Coast, and the associated risks to agriculture, infrastructure, and population displacement.

In addressing these challenges, the chapter proposes several strategies and interventions. These include risk aversion strategies to counter the impacts of sea-level rise and initiatives to mitigate the threat of diminishing water supply from the Nile. The chapter emphasizes the importance of integrating scientific advancements and sustainable practices into agricultural strategies to build a resilient agricultural sector. It also highlights the role of human resource development, institutional support, and robust legislation in this transformative journey.

Early-warning systems are highlighted as a crucial tool in managing the risks associated with climate variability. These systems provide timely information that allows for better planning and response to potential threats, thereby minimizing losses in agriculture. The chapter discusses the integration of these systems into the national agricultural framework to enhance preparedness and resilience.

Adaptation strategies are a key focus, emphasizing the need for Egyptian agriculture to evolve in response to climate change impacts. This involves developing and implementing practices that are more resilient to climatic extremes, such as droughts and heatwaves. The chapter describes various adaptive techniques being employed, including crop diversification, improved irrigation methods, and the adoption of drought-resistant crop varieties.

The optimization of water-use efficiency is another significant aspect of this chapter. Given Egypt's reliance on the Nile for its water needs and the increasing pressure from the Grand New Dam, Ethiopia, and population growth and climate change, efficient water management is vital. The chapter delves into modern irrigation techniques, water-saving technologies, and policies aimed at maximizing the utility of available water resources.

Agro-management techniques, particularly precision agriculture and AI, are discussed as innovative approaches to enhance productivity and sustainability. Precision agriculture involves the use of advanced technologies such as satellite imagery, GPS, and sensors to monitor and manage crops more efficiently. AI is employed to analyze data and make informed decisions, optimizing resource use and crop yields.

The chapter explores the role of genetic resources in bolstering the resilience of Egyptian

agriculture. It discusses the development and use of genetically modified crops and livestock that are resistant to pests, diseases, and environmental stresses. This approach is seen as critical to ensuring food security and sustainable agricultural development in the face of changing climatic conditions.

The chapter concludes by emphasizing the critical juncture faced by Egyptian agriculture, pivotal to the country's economy and food security, under the strain of climate change, limited natural resources, and rapid population growth. It calls for resilience, innovation, and adaptability in the agricultural sector, leveraging science and technology, fostering institutional reforms, and engaging in comprehensive policy development to secure a sustainable and prosperous future for Egypt's agricultural sector and its people.

The chapter also investigates the impact of climate change on Sustainable Development Goals (SDGs) and explores the opportunities arising from the outcomes of COP27, particularly in the context of loss and damage. It discusses various modalities including green transition, the adaptation fund, carbon tax, and other mechanisms, and their impact on the livelihood of Egyptian inhabitants.

Overall, the chapter provides a comprehensive view of the multifaceted efforts required to transform Egyptian agriculture into a more resilient, efficient, and sustainable system in the face of unprecedented climatic challenges.

Ch. 15: Humanity and Nature

This chapter delves into the complex relationship between humanity and nature. It becomes increasingly evident that the authors' diverse perspectives converge on several significant themes. The undeniable consensus that emerges from the four presentations is the profound interconnectedness of humans with the natural world, with the Industrial Revolution marking a pivotal moment that significantly contributed to the shaping of climate change. Collectively, these authors underscore the urgent call for shared responsibility, emphasizing that those who bear greater responsibility for the harm inflicted upon nature must also shoulder the responsibility of protecting vulnerable communities.

Nevertheless, while common ground exists in many aspects, each author brings a unique perspective, highlighting distinct nuances. Dr. Serageldin and Dr. Sharon Mijares draw our attention to the Holocene epoch as the starting point for human-induced alterations to nature, setting in motion an irreversible trajectory. Aliaa Rafea differentiates between naturally occurring climate variations and those exacerbated by human actions.

Furthermore, Dr. Serageldin, Dr. Mijares, and Dr. Rafea all stress the importance of international collaboration in addressing the intricate challenges of climate change. Dr. Serageldin and Dr. Rafea share a common belief in the indispensable role of science in confronting and navigating the complexities of our changing climate.

Spirituality emerges as a recurring theme, with Dr. Mijares, Honorable Dena Merriam, and Dr. Rafea incorporating it into their narratives, albeit through different lenses. Dr. Mijares perceives spirituality as intrinsically linked to the feminine essence of the universe. Honorable Dena Merriam shares her profound spiritual connection with a whale, encouraging humanity to listen and resonate with the diverse voices of nature genuinely. Dr. Rafea centers on introspection, proposing that the path to self-realization is rooted in a spiritual quest that inevitably deepens our bond with the natural world.

While each author contributes a unique tapestry of thoughts, their collective aspiration remains abundantly clear: preserving our planet. In all its magnificence, nature implores us to safeguard and heal its wounds. A radical shift in our collective consciousness is imperative. We must unite in thought and action, ensuring that future generations are spared from the devastating impact of nature's wrath.

Ch. 16: Protecting Vulnerable Lives and Livelihoods in Times of Climate Change

Authored by Ismail Serageldin, the chapter emphasizes the dire situation of over 2 billion people living in drylands who are highly susceptible to the impacts of climate change.

The chapter covers several key areas:

1. Climate change impact. This section deals with the undeniable reality of climate change

and its diverse manifestations, including extreme weather events and their impact on biodiversity and sea levels.

2. Capacity building for adaptation and resilience. The chapter emphasizes the importance of enhancing adaptation and resilience, especially in poorer regions, and discusses the moral responsibility of richer countries to assist in these efforts.

3. Vulnerabilities in drylands. It focuses on the unique challenges faced by populations in drylands, such as water scarcity, soil degradation, and limited economic opportunities.

4. Human and institutional capacity. The importance of investing in human resources, health, education, and institutional development as a means to sustainable development in poor countries is highlighted.

5. Migration issues. The chapter addresses various facets of migration, including internal and international migration, and the phenomenon of 'brain drain'.

6. Gender dimensions. It touches on the differential impacts of climate change on women, highlighting their crucial role in adaptation and resilience.

7. Technological and scientific solutions. The potential of science and technology, including ICT and new biological techniques, in addressing climate change issues is explored.

8. Financing and funding. The need for a significant shift in traditional mechanisms of aid and international finance is highlighted. The authors suggest that current financial structures are inadequate to address the challenges posed

by climate change. The chapter proposes more effective and sustainable funding solutions, particularly for vulnerable regions like drylands, stressing the need for developed countries to play a more substantial role in providing financial assistance. This section delves into the complexities of funding climate change initiatives and underscores the urgency of rethinking financial strategies to combat environmental challenges effectively.

Ch. 17: The Day after COP28

This chapter addresses and discusses what is required to employ the best of science and technology, policy, enhancing coping and adaptive capacity, and ethical consideration to save mankind and humanity and cater for the most vulnerable populations on Earth.

The chapter sheds light on the major outcomes of COP27 and COP28 and major international meetings: G20 New Delhi Leaders' Declaration, 9–10 September 2023 and African Leaders' Nairobi Declaration on Climate Change, 4–6 September 2023 (African Union, 2023; G20, 2023); in addition to pre-COP27 and 28 international webinars and workshops focusing on the impact of climate change in dry areas with emphasis on coping and adaptive capacity.

It concludes by stressing major elements related to action required (policy, funding, and legislation). It calls for a new world order to facilitate the improvement of the people's livelihoods and resilience in the face of climate change.

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