Wajid Nasim Jatoi · Muhammad Mubeen ·
Muhammad Zaffar Hashmi · Shaukat Ali ·
Shah Fahad · Khalid Mahmood *Editors*

Climate Change Impacts on Agriculture

Concepts, Issues and Policies for Developing Countries

Springer

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ISBN 978-3-031-26691-1 ISBN 978-3-031-26692-8 (eBook)
https://doi.org/10.1007/978-3-031-26692-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Climate extremes and slow onset events undermine the efforts of developing countries to eradicate poverty and promote social equity. Social security presents an opportunity to develop inclusive comprehensive risk management strategies to address the damage from climate change. However, research and policy on climate change and social protection remain limited in scope. This book aims to address this gap by presenting a number of conceptual arguments that can provide a basis for a wider discussion on principles and considerations which should be embedded in the design of national climate-responsive social security strategies and plans.

Agriculture is a key sector in developing countries in terms of economic growth and social well-being of the poor countries. Adapting and building resilience to climate change means increasing agricultural productivity and incomes and reducing greenhouse gases emissions. This is an approach to apply the technical, policy, and investment measures to get sustainable agricultural growth in the sectors of grain, fruit, vegetable, fiber, feed, livestock, fisheries, and forest under climate change. A number of strategies can be adopted to achieve the objectives of climate resilience in agriculture.

Getting there will not be easy. We need to take immediate action to change farming practices of developing countries to make our food system much more climate resilient. How we can achieve net zero without compromising enough harvest and quality? How could we cultivate our land better, and use appropriate irrigation, fertilizers, and pesticides to make our food system much more productive? We need to revive our agriculture by promoting a centuries-old proven practice of conservation agriculture as climate-smart agriculture to build a more resilient system to address these climate change threats.

These innovations include protecting our natural capital, promoting minimum or zero tillage leading to less soil disturbance, improving soil conservation using crop residues, use of crop diversification with rotation and intercropping strategies, improving water use efficiency using raised bed planting methods, use of integrated pest management, reducing post-harvest losses, and developing supply chains sharing fair margins from producers to end user.

Promoting sustainable agriculture in developing countries can be possible through a digital connectivity model using mobile phone power to promote these sustainable practices linking with supply chains. They can drive the change to incentivize farmers to use less water and less chemicals. We need a step change in thinking through connecting farm to fork, farmer to consumers. Every one of us has the responsibility to play a role including consumers in sustainable consumption, zero waste, buying products with provenance and traceability, supply chains promoting sustainable and fair trade, input suppliers, and machinery providers. Similarly, farmer should be aware about judicious use of inputs, chemicals and pesticides, water management, banks, insurance industry offering green banking, and financial products.

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Vehari, Pakistan — Muhammad Mubeen
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Preface

Feeding more than nine billion by 2050 is a mammoth task for our fragile food production system which is facing an enormous challenge from depleting natural resources and the cruelty of climate change calamities. The food system has to run fast more than double—70% more food to meet the demands of the increased population. It has been predicted that if our planet becomes 2.0 °C warmer in average temperature, this will lead to a more than 20 to 40% reduction in cereal grain production, particularly in Asia and Africa. The food equation is simply going reverse instead of incremental. More than 828 million people do not have enough food and face the risk of malnutrition. There is a looming threat from invasive species of pests and diseases with climate change. The soils have lost their vigor with intensive farming systems and the use of chemicals. We have lost biodiversity. According to WWF Living Planet Report, the world has seen an average 68% drop in mammal, bird, fish, reptile, and amphibian populations since 1970. The crops and animal species are facing an increasing risk of disease and mortality or failure due to losing resistance to this grand challenge. Although modern genomics has opened a new window of opportunity. But these gene editing technologies are facing both ethical and regulatory hurdles. Policymakers are debating the pros and cons of scientific advancements in gene manipulation technologies. The blanket use of pesticides has led to the increased build of pesticide resistance, and the risk of crop failure is getting more common in the field due to heat, drought, flooding, pests, and disease outbreaks. The existing food system plays a negative role in climate change through a 24% contribution to GHG emissions. The reliance of agriculture on freshwater consumption is more than 70%. The world has seen the consequence of the recent COVID pandemic and manmade crises.

Although more than 80% of the human causes of adverse climate change are attributed to development activities undertaken by the advanced industrial nations, almost 85% of the negative consequences of climate change are pitiably borne by the developing countries of the world. It is imperative that long-term low greenhouse gas emission development strategies should be adopted by developed countries in particular and by developing countries in general. Although industrial nations are to adopt GHG reduction mechanism on urgent basis, the emerging ones need to curtail GHG till middle of the century or even later. The advanced countries are also urged to strengthen adaptation action and support (climate finance) for developing countries in their struggle to combat climate change. Developing countries may also establish other forms of targets for climate action plans like promotion of renewable energy projects. The capacity building is a key to success. The book therefore finds the solution in autonomous development strategies, which are environment friendly. This demands proactive policy measures which are synergetic—that is, in addition to global and regional networks, an inter-ministry, inter-agency, and inter-departmental approach is needed, since the phenomenon of climate change is sectorally cross-cutting.

Bahawalpur, Pakistan Wajid Nasim Jatoi

Acknowledgment

This book is the outcome of the dedication and efforts of editors Prof. Dr. Wajid Nasim Jato (Director, International Center for Climate Change, Food Security & Sustainability (ICCFS) & Department of Agronomy, Faculty of Agriculture & Environment (FA&E), The Islamia University of Bahawalpur-Pakistan), Dr Muhammad Mubeen, Dr. Muhammad Zaffar Hashmi, Dr. Shaukat Ali, Dr. Shah Fahad, and Dr. Khalid Mahmood. We would like to thank them for their entire support to make the completion of this book possible. We would also like to sincerely thank our valuable reviewers. Many eminent researchers and academicians have excellent guidance and support for preparation of this international book. We highly appreciate the kind support and encouragement from worthy Vice Chancellor/Patron-in-Chief CSSC, Engr. Prof. Dr. Athar Mahboob (Tamgha-e-Imtiaz); Patron CCSC, Prof. Dr. Shazia Anjum, Dean Faculty of Chemical and Biological Sciences; Prof. Dr. Tanveer Hussain Turabi, Dean, Faculty of Agriculture & Environment, IUB, entire team of Consortium on Climate Change, Sustainability and Conservation (CCSC); Prof. Dr. Asif Naveed Ranjha; Dr. Abid Rashid Gill; Dr. Nargis Naz; Dr. Muhammad Abdullah; and Ms. Farkhanda Tehseen, Principal Officer, Estate Care & Space Management/Director, Planning and Development, The UB, Pakistan. Dr. Abid Shahzad, Director, Directorate of International Linkages, IUB; Prof. Dr Abou Bakar Treasurer, IUB; Dr. Sheikh Safeena Sidiq, Director/Senior Medical Officer, Women Health Care Center & Maternity Home, IUB; Mr. Rizwan Majeed, Director, Information Technology, Mr. Shahzad Khalid, Public Relation Officer, IUB; Mr. Salman Mahmood Qureshi, Director, IUB-Directorate of Sustainable Toursim (IUB-DoST); Mr. Waseem Ahmad Siddiqui, Principal Staff Officer to Vice Chancellor, IUB; Mr. Muhammad Khalid Sheikh, Executive Secretary to Vice Chancellor IUB. Mr. Maj. Syed Ejaz Hussain Shah, Chief Security Officer, IUB.; Dr Muhammad Khalil-ur-Rehman, IUB. Mr. Nasir Mehmood Elia, CEO, Bristol Pvt Ltd, Pakistan; Mr. Sartaj Alam, CEO Better Business Matrix (BBM); Dr Muneeb Bukhari; and Ai-Hankao International Study and Exam Center that are not to be ignored.

First Editor (Wajid Nasim Jatoi) is highly thankful to the support and cooperation given by all colleagues from the Department of Agronomy, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur, Pakistan, is highly acknowledged and commendable. Dedication and appreciation go to my Family that includes Mrs. Muhammad Hanif Khan Jatoi, Mrs. Haji Muhammad Pervaiz Khan, and my elder brother Mr. Muhammad Sajid Nasim Khan and their cute families), to whom I am here to be able to do all my professional career. Last but not least, being First Editor (Wajid Nasim Jatoi), my family is my pride, I am very much thankful father-in-law (Mr. Haji Manzoor Hussain Khan), mother-in-law (Mrs. Abida Parveen) and my dear wife (Mrs. Neelam Manzoor) and my cute kids Mr. (Muhammad Mosa Nasim and Ms. Marium Fatima), similarly, I am very much thankful to my brothers-in-law (Mr. Hassan Raza Khan, Mr. Mohsin Raza Khan, Mr. Hasnain Raza Khan) for their kind support and care all the times.

The moral support of Muhammad Akbar, Malik Ahmad Bakhsh Bhutta, Prof. Dr. Nazim Hussain, Prof. Dr. Zahid Ata Cheema, Prof. Dr. Abid Hussain, Prof. Dr. Ashfaq Ahmad Chattha, Prof. Dr. Syed Aftab Wajid, Prof. Dr. Asghari Bano, Dr. Muhammad Shahid, Dr. Hafiz Faiq Siddique Gul Bakhat, and Mr. Waseem Akram has been really helpful in achieving the task. At the end, we are highly thankful to International Publisher (Springer Nature), its administration, and all the respected members who have supported a lot for entire duration from proposal till publication of this book.

Bahawalpur, Pakistan Wajid Nasim Jatoi

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About the Editors

Wajid Nasim Jatoi serving as Professor in Department of Agronomy, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur (IUB), Pakistan. Before joining IUB, he served the Department of Environmental Sciences, COMSATS University Islamabad (Vehari Campus), Pakistan for 8 years, and Quaid-i-Azam University Islamabad, Pakistan for 1 year at different positions. Furthermore, he completed his Post-Doctorates from France and from Australia in field of Climate Change & Food Security Sustainable/Precision Agriculture. Before Post-Doctorates, he completed his PhD training from the College of Agriculture and Environmental Sciences, The University of Georgia, USA. Recently he is also working as Focal Person in the Consortium on Climate Change, Sustainability and Conservation (CCSC), and as Director at the International Center for Climate Change, Food Security and Sustainability (ICCFS), The Islamia University of Bahawalpur, Pakistan (https://ccsc.iub.edu.pk/). Furthermore, he has completed many national and international research projects in collaboration with Columbia University, USA; International Food Policy Research Institute (IFPRI), USA; CIHEAM-IAMM France; etc. He has produced more than 50 undergraduate and postgraduate students. He has published more than 100 peer reviewed research publications (with more than 400 Impact Factor) and organized more than 50 national and international conferences/seminar's/workshop and attended more than 50 national and international conferences/seminars/workshops as invited/keynote speaker. The detailed information can be seen from link https://www.iub.edu.pk/author/Wajid.Nasimjatoi, also first editor of international book "Building Climate Resilience in Agriculture" https://link.springer.com/book/10.1007/978-3-030-79408-8

Muhammad Mubeen has been working as Tenured Associate Professor at the Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus (Pakistan) since April, 2022. His areas of interest include agronomy, climate change and agro-meteorology, crop growth modeling, remote sensing and GIS, and water management. He has expertise in cropping system model "Decision Support System for Agro-technology Transfer (DSSAT) and GIS softwares (ArcGIS and ERDAS)." He has over 100 publications in national and international peer reviewed journals and books over his areas of expertise. He is reviewer of many national and international well-reputed journals. He is also editor of international book *Building Climate Resilience in Agriculture-Theory, Practice and Future Perspective*.

Muhammad Zaffar Hashmi is working as Associate Professor in Department of Environmental Science, The University of Lahore. Before he was Assistant Professor in Environmental Engineering at the Department of Chemistry at COMSATS University Islamabad Campus, Pakistan. Dr. Hashmi works on multiple water, soil, air, and health-related issues and has expertise in developing environmentally sustainable and feasible technologies.

Shaukat Ali holds PhD in Meteorology from the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS). He also has an LLB degree with a special focus on Environmental Law. Currently, He is working as Senior Scientific Officer in Global Change Impact Studies Centre (GCISC), Ministry of Climate Change, Government of Pakistan. He started his career as a Lecturer at the University and then worked for different government departments in Pakistan. Dr Ali has also worked as a consultant for

Asian Development Bank. He is a visiting research scholar to Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, International Institute for Applied Systems Analysis (IIASA), Vienna, Austria, and APEC Climate Center (APCC), Busan, Korea. He is leading a regional research project (CRRP2018-04MY-Ali) funded by Asia Pacific Network on Global Change Research (APN). His peer-reviewed publications cover topics ranging from climate modelling, future projections of climate, extreme events, and impact assessment of climate change. He is involved in multiple efforts to communicate scientific research on climate change to the public and policymakers.

Shah Fahad is working as Assistant Professor at the Department of Agronomy, Abdul Wali Khan University Mardan, Khyber Pakhtunkhwa, Pakistan. He obtained his PhD in Agronomy from Huazhong Agriculture University, China, in 2015. After doing his postdoctoral research in Agronomy at the Huazhong Agriculture University (2015–17), he accepted the position of Assistant Professor at the University of Haripur. He has published over 430 peer-reviewed papers (Impact factor 1834) with more than 370 research and 60 review articles, on important aspects of climate change, plant physiology and breeding, plant nutrition, plant stress responses and tolerance mechanisms, and exogenous chemical priming-induced abiotic stress tolerance. He has also contributed 80 book chapters to various book editions published by Springer, Wiley-Blackwell, and Elsevier. He has edited 17 book volumes, including this one, published by CRC press, Springer, and Intech Open. He won Young Rice International Scientist award and distinguish scholar award in 2014 and 2015, respectively. He won 17 projects from international and national donor agencies. Dr. Shah Fahad figured in the Clarivate's 2021 and 2022 lists of Highly Cited Researchers. His name included among the top 02% scientists in a global list compiled by the Stanford University, USA.

Khalid Mahmood has a PhD in Agriculture Economics from the University of Gottingen, Germany, and is a Fellow of the Higher Education Academy of England. For the last decade, he is working with the Rothamsted Research Institute in the UK which has a history of the world's longest-running experience on crop nutrition starting back in 1843. In the past, he worked with Federal Agri Research Von Thunen Institute, Germany, Royal Agriculture University, UK, and Agriculture and Horticulture Development Board (AHDB), UK. He is leading in developing research and partnerships in sustainable agriculture, soil health, bio-saline agriculture, and smart crop protection, especially innovative solutions for climate-smart agriculture in the Middle East and North Africa.

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Abbreviations

AATF	African Agricultural Technology Foundation
ACR	American Carbon Registry
ACS	Active Canopy Sensors
ADB	Asian Development Bank
ADCM	Agricultural Digital Camera Model
AF	Adaptation Fund
AFOLU	Agriculture, Forestry and Other Land Use
AIDS	Acquired Immune Deficiency Syndrome
AJK	Azad Jammu and Kashmir
AOS	Alberta Offset System
APEC	Asia-Pacific Economic Cooperation
AR6	Intergovernmental Panel on Climate Change Expert's Production of Assessment Report
ARDL	AutoRegressive Distributed Lag Method
ARIS	Annual Relative Irrigation Supply
AWC	Available Water Capacity
BISP	Benazir Income Support Program
BRICS	Brazil, Russia, India, China, and South Africa
CAR	Climate Action Reserve
CBA	Cost-Benefit Analysis
CC	Climate Change
CCA	Climate Change Adaptation
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Storage and Utilization
CDM	Clean Development Mechanism
CDPC	Computerized Data Processing Centre
CEC	Cation Exchange Capacity
CERES	Crop Environment Resource Synthesis
CEWRE	Center of Excellence in Water Resources Engineering
CFC	Chlorofluorocarbon
CFI	Comparative Farm Irrigation cost

CGPI	Clean Green Pakistan Index
CH4	Methane
CIF	Climate Investment Fund
CMI	Cell Membrane Integrity
CO_2	Carbon Dioxide
CO_2e	CO_2-equivalent
COP	Conference of Parties on Climate Change
COVID-19	Coronavirus Disease 2019
CRED	Centre for Research on the Epidemiology of Disasters
CSA	Climate-Smart Agriculture
CSM	Cropping System Model
CT	Condensed Tannin
DAF&F	Department of Agriculture, Fisheries and Forestry
DAR	Delivery Act Ratio
DLIS	Desert Locust Information Service
DNA	Deoxyribonucleic acid
DRIAS	Double Recirculatory Integrated Aquaculture system
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSSAT	Decision Support System for Agrotechnology Transfer
DVI	Difference Vegetation Index
EC	Electrical Conductivity
ENSO	El Nino and the Southern Oscillation
EOBI	Employees Old-age Benefits Institution
EPA	Environmental Protection Agency
EU	European Union
FA	Fatty Acids
FA&E	Faculty of Agriculture and Environment
FAO	Food and Agriculture Organization
FBR	Federal Board of Revenue
FC	Field Capacity
FCPF	World Bank's Forest Carbon Partnership Facility
FDI	Foreign Direct Investment
FREL	Forest Reference Emission Level
G7	Group of Seven Countries
G7	Seven Industrialized Nations
GAB	Genomic-Assisted Breeding
GB	Gilgit Baltistan
GBS	Genotyping by Sequencing
GCF	Green Climate Fund
GCM	General Circulation Models
GDP	Gross Domestic Product
GDVI	Green Difference Vegetation Index
GEF	Global Environment Facility
GFSS	Global Food Security programmer

GHGs	Greenhouse Gases
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GLONASS	Russia's Global Navigation Satellite System
GMM	Generalized Method Moment
GMOs	Genetically Modified Organisms
GNSS	Global Navigation Satellite System
GOP	Government of Pakistan
GPS	Global Positioning System
GRVI	Green Ratio Vegetation Index
GS	Gold Standard
GWAS	Genome-Wide Association Studies
GWP	Global Warming potential
HCFC	HydroChloroFluoroCarbons
HFCS	High Fructose Corn Syrup
HFCs	HydroFluoroCarbons
HIV	Human Immunodeficiency Virus
HLPF	High-Level Political Forum
HSPs	Heat Shock Proteins
ICCFS	International Centre for Climate Change, Food Security and Sustainability
ICT	Information Communications Technology
IFAD	International Fund for Agricultural Development
IFF	Integrated Fish Farming
IFFS	Integrated Fish Farming Systems
ILO	International Labour Organization
IMF	International Monetary Fund
INRES	Institute of Crop Science and Resource Conservation
IPCC	Intergovernmental Panel on Climate Change
IPRS	In Pond Raceways system
IR	Infrared
IRR	Internal Rate of Return
IUB	The Islamia University of Bahawalpur
JI	Joint Implementation
KASP	Kompetitive Allele-Specific PCR
KPK	Khyber Pakhtunkhwa
LACCs	Latin American and Caribbean Countries
LDCs	Least Developed Countries
LID	Low Impact Development
MAD	Management Allowable Deficit
MAS	Marker-Assisted Selection
MDBs	Multilateral Development Banks
MDE	Monetary Delivery Efficiency
MDG	Millennium Development Goals
MLC	Maximum Likelihood Classifier

MP	Montreal Protocol Basel Convention on the Control of Transboundary Movements of
N2O	Nitrous Oxide
NAMC	National AgroMet Centre
NAP	National Adaptation Plan
NAPAs	National Adaptation Programmes of Action
NASA	National Aeronautics and Space Administration
NDCs	Nationally Determined Contributions
NDVI	Normalized Difference Vegetation Index
$NDVI_{NNRS}$	NDVI of the Non-N-Enriched Strip
$NDVI_{NRS}$	NDVI of N-Enriched Strip
NERICA	New Rice for Africa
NF_3	Nitrogen Trifluoride
NGI	Normalized Green Index
NGO	Non-Governmental Organizations
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NOU	National Ozone Unit
NPBTs	Novel Plant Breeding Technologies
NPV	Net Present Value
NRDC	Natural Resources Defense Council
NRI	Normalized Red Index
NSA	Nutrition-Sensitive Agriculture
NUE	Nitrogen Use Efficiency
NUST	National University of Science and Technology
O&M	Operational and Maintenance
ODM	Oligonucleotide Directed Mutagenesis
ODP	Operating Department Practitioner
OECD	Organisation for Economic Co-operation and Development
OM	Organic Matter
OTC	Open Top Chambers
PA	Precision Agriculture
PCA	Principal Component Analysis
PCT	Pacific Carbon Trust
PET	Potential Evapotranspiration
PFCs	Perfluorocarbons
PFCs	Perfluorochemicals
PMAS	Program Management and Support
PMF	Probable Maximum Flood
PNW	Pacific Northwest
ppm	parts per million
PPO	Polyphenol Oxidase
PSDP	Public Sector Development Programme
PSMD	Potential Soil Moisture Deficit
PSSS	Provincial Employees Social Security Scheme

PV	Present Values
PV	Pollen Viability
PWP	Permanent Wilting Point
RAD	Running Allowed Deficit
RAS	Recirculatory Aquaculture system
RCR	Recovery Cost Ratio
RDI	Regulated Deficit Irrigation
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RETs	Renewable Energy Technologies
RFPPs	Rice-Fish Production Practices
RGGI	Regional Greenhouse Gas Initiative
RGVI	Relative Green Vegetation Index
RNDVI	Relative Normalized Difference Vegetation Index
ROS	Reactive Oxygen Species
R-PP	Readiness Preparation Proposal
RS	Remote Sensing
RSS	Remote Sensing Satellites
RST	Remote Sensing Technology
RVI	Ratio Vegetation Index
RWC	Relative Water Cost
SAMD	Spectral Angle Mapper Division
SDG	Sustainable Development Goals
SF_6	Sulfur Hexafluoride
SHF	Small-Holder Farmer
SII	Social Insurance Institute
SNPs	Single-Nucleotide Polymorphisms
SOM	Self-Organizing Maps
SP	Social Protection
SPAD	Soil-Plant Analysis Development
SRM	Storage Resource Management
SSK	Sosyal Sigortalar Kurumu
SSP	Sehat Sahulat Program
SVN	Support Vector Networks
SWD	Soil Water Deficit
TALEN	TAL Effector Nucleases
TAW	Total Accessible Water
TBTTP	Ten Billion Tree Tsunami Programme
TT	Threshold Temperatures
UAV	Unmanned Arial Vehicles
UHI	Urban Heat Islands
UNCCD	United Nations Convention to Combat Desertification
UNCCS	UN Climatic Change Secretariat
UNDP	United Nations Development Programme
UNEP	UN Environment Program
UNFCCC	United Nations Framework Convention on Climate Change

UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
VCS	Verified Carbon Standards
VOCs	Volatile Organic Compounds
VRA	Variable Rate Application
VRT	Variable Rate Technology
WHO	World Health Organization
WHZs	Weight-for-Height z-scores
WMO	World Meteorological Organization
WOP	Without Project
WP	With Project
WRI	World Risk Index
WUE	Water Use Efficiency
YM	Yield Monitoring

Part I
Climate Change Concepts and Issues for Developing Countries

Global Framework on Climate Change

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Abstract At the global level, climate change is a foremost threat for food security. It is extensively recognized that variations in temperature, precipitation, sea water level, and concentrations of greenhouse gases (GHGs) in the environment will have increasingly distressing influences on both crop production and quality. Global temperature has increased almost 1 °C up to date, and it is predicted that it will be increased by 2.5–4.5 °C by the end of this century. The effects of climatic changeability on crop efficiency, along with food security, is a main theme of global concern. It is well documented that crop phenology, productivity, and quality are significantly affected due to climate change at local, regional, and global levels. Therefore, the global framework (Kyoto Protocol and Paris Agreement) recommendations must be fully endorsed and act upon for reduction of greenhouse gas emission to save our planet.

Keywords Greenhouse gases · Crop phenology · Nutrition quality · Kyoto protocol · UNFCCC

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_1

1 Introduction

The main problem in the world is climate change, which is one of the major threats for food security across all continents, both currently and in the future. Climate change can be defined as a noteworthy change in averaged values of the climatological parameters, for example, temperature and rainfall, for which means have been calculated for a longer period (Porter et al. 2019; Ikhuoso et al. 2020). Climate change is a worldwide hazard for the food as well as its quality in developed and developing countries. As a release of all greenhouse gases in the atmosphere is increasing, the air temperature is correspondingly increasing as a result of the greenhouse effect. It is projected that our planet will be hotter in the coming decades, with average air temperature increasing at a rate of approximately 0.2 °C in each decade to the succeeding decades toward the end of this century. Moreover, estimates suggest that the global temperature will be increased from between 2.5 and 4.5 °C at the end of this century due to the enhancement in the concentration of greenhouse gases in the environment (Pathak et al. 2018; Wang et al. 2018; Ortiz et al. 2021; Gordeev et al. 2022). The averaged global temperature is rising uninterruptedly, and it is projected that it will have increased by 2 °C by the end of this century, which could have a considerable impact on the global economy. The concentration of carbon dioxide, which is the largest contributor in terms of the presence of these gases in the atmosphere, is rising at a distressing speed. When only taking into account the impact of CO_2, it has caused more growth as well as plant productivity because of the acceleration of photosynthetic processes; nevertheless, raised temperature counterbalances this impact because heat stress causes an enhanced respiration rate in plants as well as evapotranspiration rate, increased pest attacks, a shifting of weed diversity, and also earliness of phenological stages (Abegunde et al. 2019; Kogo et al. 2021). The historical few decades indicated that significant variations in climatic conditions across the globe were due to increased human activities, which changed the composition of the earth's atmosphere. The concentrations of greenhouse gases, such as methane, carbon dioxide, and nitrous oxide, have enhanced by 150, 40, and 20%, respectively, from their pre-industrial revolution levels (IPCC 2014). The release of CO_2, which contributes a higher share in greenhouse gas concentrations (Sathaye et al. 2006; Cui and Xie 2022), had risen to 36.5 billion tons in 2014, up from 22.1 billion tons in 1990 (Abeydeera et al. 2019). The earth's temperature has increased at an average of 0.15 to 0.20 °C per ten years starting from 1975 (NASA 2020), and it is predicted that the temperature may increase between 1.4 and 5.8 °C by the end of this century. Emission of GHGs

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principally carbon dioxide by fossil fuel burning as well as other greenhouse gases like nitrous oxide and methane along with chlorofluorocarbons significantly contributed to global climate change. Concentration of carbon dioxide in air had enhanced to 411.43 ppm in 2019 from 315.98 ppm in 1959 at global level. Carbon dioxide contributes a chief percentage in concentrations of greenhouse gases in air: 65% as a burning of fossil fuels as well as industrial processes and 11% by forestry as well as others land usage; it is followed by methane (CH_4), nitrous oxide, and fluorinated gases contributing 16, 6, and 2%, respectively. Earlier from 1750, emission of carbon dioxide from burning of fossil fuels was insignificant; nevertheless, it was augmented quickly due to industry revolution (Malhi et al. 2021; Husson et al. 2022).

2 Global Impact of Climate Change on Crop Phenology

Phenological stages and phases of crops have been significantly influenced due to climate change across the world (Tables 1 and 2). Growth along with the development of all plants is associated with meteorological parameters, photoperiod, and growing degree days that enable them responsive to the environmental conditions (Luo et al. 2014; Wang et al. 2015; Fatima et al. 2020). Climate change caused acceleration of phenological stages and resulted in shortening of phenological phases. Earth temperature is increasing because of human activities, for example, combustion of fossil fuels as well as cutting of forest tress for the purpose of building formation (Estrella et al. 2007; Abbas et al. 2017). The enhancement in temperature causes disruption to growth as well as developmental stages of agriculture crops. Disturbance mostly causes a change in phenology of fruit trees, vegetables, and agronomic crops and ultimately exerted a negative impact on economic production (Wang et al. 2016). Crop phenology adjustment is utmost noteworthy character of crop as an adaptation strategy. Phenology changes occurring in both spatial and temporal basis provide sturdy indication of biological effect of increasing climate change trend (Oteros et al. 2015; Xiao et al. 2016). Changes in the phenology seasonality have directly and indirectly influences on the natural vegetation and resource use efficiencies (Chmielewski et al. 2004; Nasim 2007, 2010). The climatic change tendency has been clearly indicated by the acceleration of crop growth rate and shortened crop-growing periods (He et al. 2015; Liu et al. 2019). The phenological stages are extremely sensitive to climatic changes and have a significant influence on the carbon balance. Crop phenology is influenced by larger fluctuations in the environmental conditions as a result of climate change (Rezeai et al. 2017). Moreover, periods of phenology stages are also associated with carbon dioxide assimilation, consequently a shifting in phenology influences on the crop productivity and ultimately overall crop production (Wang et al. 2008; Croitoru et al. 2012; Ahmad et al. 2019; Irfan et al. 2022; Hussain et al. 2022a, b).

Table 1 Observed changes in trend of phenology of agronomic crops in different countries

Crop	Country	Period	Phenological stages (early/delay days/decade)				Phenological phases (reduction days/decade)			References
			Sowing	*Emergence*	*Anthesis*	*Maturity*	*S-A*	*A-M*	*S-M*	
Spring maize	Pakistan	1980–2014	[a]E4.6	E3.7	E7.1	E9.2	2.4	1.9	4.6	Abbas et al. (2017)
Autumn maize	Pakistan	1980–2014	[b]D3.0	D1.9	D2.8	D4.4	5.5	2.2	7.8	Abbas et al. (2017)
	China	1981–2010	D5.4	D4.8	D5.2	D7.1	1.3	0.8	2.2	Wang et al. (2016)
	China	1990–2012	D10.0	D9.4	D10.5	D5.6	4.1	3.9	5.7	Li et al. (2014a)
	China	1981–2008	D8.1	D7.8	D6.2	D3.7	5.2	2.6	3.7	Xiao et al. (2016)
	America	1981–2005	E3.9	E3.2	E1.7	E2.9	2.9	1.8	3.0	Sacks and Kucharik (2011)
	China	1992–2013	E1.3	E1.0	E4.1	E2.7	1.1	2.0	3.0	Mo et al. (2016)
	Germany	1961–2000	E4.5	E4.1	E5.6	E8.8	3.1	7.2	4.9	Chmielewski et al. (2004)
	China	1981–2000	D1.7	D1.5	D3.3	D5.5	2.4	2.2	2.8	Tao et al. (2006)
	China	1981–2009	D5.0	D3.1	D4.0	D6.7	1.0	2.7	3.5	Liu et al. (2017)
	China	1992–2013	D3.5	D3.2	D1.8	D1.5	1.9	3.3	1.5	Mo et al. (2016)
	China	1981–2010	D8.7	D6.9	D4.6	D2.2	4.6	2.4	6.2	Liu et al. (2019)
Spring sunflower	Pakistan	1980–2016	E6.6	E6.3	E3.8	E2.2	2.8	1.6	4.4	Tariq et al. (2018)

Autumn sunflower	Pakistan	1980–2016	D5.7	D5.4	D3.1	D1.8	2.5	1.2	3.8	Tariq et al. (2018)
Canola	Pakistan	1980–2014	D6.0	D3.1	D3.3	D1.9	2.7	4.3	1.4	Ahmad et al. (2017a)
	China	1981–2009	D9.0	D8.2	D1.6	D1.9	5.5	3.1	5.0	Wang et al. (2012)
	Germany	1960–2013	E0.4	E0.3	E3.1	E2.0	2.9	1.1	3.2	Rezaei et al. (2017)
Cotton	Pakistan	1980–2015	E5.4	E5.1	E2.9	E1.1	2.4	1.8	4.2	Ahmad et al. (2017b)
	China	1981–2004	D10.9	D9.0	D13.9	D16.4	2.5	12.0	9.0	Wang et al. (2008)
	Australia	1980–1999	E1.9	E4.1	E5.1	E8.16	3.3	2.5	6.8	Luo et al. (2014)
	China	1981–2010	E2.4	E2.6	E1.6	E2.2	1.7	3.4	5.2	Huang and Ji (2015)
	China	1981–2012	E0.3	E1.3	E0.9	E2.7	1.9	2.0	3.5	Wang et al. (2017)
			Planting	*Stem elongation*	*Peak population*	*Harvesting*	*P-S*	*S-P*	*P-H*	
Spring sugarcane	Pakistan	1980–2014	E2.8	E4.4	E5.0	E6.4	1.6	0.5	3.5	Ahmad et al. (2016)
Autumn sugarcane	Pakistan	1980–2014	D6.5	D4.3	D3.1	D2.1	2.2	1.2	4.4	
Sugarbeet	Germany	1961–2000	D6.9	D5.5	D5.2	D3.2	2.9	4.4	5.2	Chmielewski et al. (2004)
	Germany	1951–2004	D1.8	D1.6	D2.7	D5.9	1.2	2.3	3.1	Estrella et al. (2007)
Soybean	America	1981–2005	E2.5	E1.6	E2.8	E1.9	1.8	2.0	3.4	Torrion et al. (2011)

[a]Early; [b]Delay

Table 2 Observed changes in trend of phenology of agronomic crops in different countries

Crop	Country	Period	Phenological stages (early/delay days/decade)				Phenological phases (reduction days/decade)			References
Wheat			*Sowing*	*Emergence*	*Anthesis*	*Maturity*	*S-A*	*A-M*	*S-M*	
	China	1983–2004	[a]E13.2	E9.8	E11.0	E10.8	16.1	8.2	12.3	Wang et al. (2008)
	Pakistan	1980–2014	[b]D9.5	D1.3	E5.3	E5.4	5.5	4.6	5.7	Ahmad et al. (2019)
	China	1981–2005	E7.6	E6.3	E2.0	E4.8	3.8	4.1	5.8	Li et al. (2016)
	Spain	1986–2012	E3.8	E2.6	E5.2	E2.9	4.6	5.1	7.2	Oteros et al. (2015)
	Australia	1995–2016	E3.9	E2.8	E7.5	E5.8	6.6	7.9	10.7	Luo et al. (2018)
	China	1981–2009	D1.2	D1.3	D3.7	D3.1	5.0	3.1	4.3	He et al. (2015)
	Argentina	1971–2000	D3.0	D2.9	D4.2	D4.9	7.5	6.9	5.4	Sadras and Monzon (2006)
	China	1980–2009	D4.1	D3.7	D6.3	D8.1	6.1	2.3	3.6	Wang et al. (2013)
	Romania	1971–2006	D3.5	D2.5	D2.2	D3.0	2.3	3.2	4.0	Croitoru et al. (2012)
	China	1981–2010	D9.0	D8.5	D11.0	D16.2	3.7	2.5	1.3	Liu et al. (2018)
	China	1981–2009	D1.5	D1.7	D2.1	D2.5	2.0	1.8	3.1	Xiao et al. (2013)
	Germany	1952–2013	E2.0	E1.8	E4.1	E5.0	1.9	0.8	2.7	Rezaei et al. (2018)
	China	1981–2000	E3.4	E2.9	E3.0	E3.3	0.4	0.3	1.0	Tao et al. (2006)
Oat	Germany	1959–2009	E1.1	E1.8	E9.7	E10.7	7.9	13.9	9.4	Siebert and Ewert (2012)
	Germany	1951–2004	E1.5	E1.2	E4.9	E6.4	3.4	1.5	4.9	Estrella et al. (2007)
Barley	Lithuania	1961–2015	E1.7	E2.8	E1.1	E0.4	1.0	1.6	2.2	Sujetovienė et al. (2018)
	Spain	1986–2008	D2.8	D1.9	D2.7	D3.5	1.6	2.1	3.7	García-Mozo et al. (2010)
Rye	Poland	1957–2012	D2.2	D1.9	D4.0	D3.6	1.8	1.4	3.2	Blecharczyk et al. (2016)
	Germany	1960–2013	E1.0	E1.2	E1.8	E1.6	2.9	3.1	4.5	Rezaei et al. (2017)

			Sowing	*Transplanting*	*Anthesis*	*Maturity*	*S-T*	*A-M*	*T-M*	
Rice	Pakistan	1980–2014	E7.9	E6.6	E5.0	E5.0	1.4	4.1	6.4	Ahmad et al. (2019)
	Madagascar	2008–2010	E5.4	E3.2	E6.2	E4.8	4.1	3.2	6.2	Shrestha et al. (2013)
	China	1981–2006	D1.0	D1.4	D2.7	D3.1	3.3	1.2	4.1	Zhang et al. (2013)
	China	1981–2000	E5.7	E5.2	E6.2	E3.6	0.5	2.6	3.1	Tao et al. (2006)
	China	1992–2013	D2.2	D1.9	D2.8	D3.4	0.8	1.7	2.4	Wang et al. (2019b)
	China	1981–2012	D4.9	D4.2	D3.8	D5.2	2.4	3.2	5.1	Hu et al. (2017)
	China	1981–2009	D3.7	D3.0	D2.0	D4.0	2.8	1.9	2.2	Zhang et al. (2014)
	China	1981–2009	D6.5	D5.8	D1.5	D2.4	2.9	1.6	5.2	Bai et al. (2019)

Source: Fatima et al. (2020)

[a]Early; [b]Delay

3 Global Climate Change Impact on Crop Productivity

Climatic changes have significant potential to affect crop production directly through both heat and drought stresses. Climate change can also have an indirect influence on crop yield through reducing fertilizer efficiency, and increasing both pathogen occurrence and pest infestation. A number of scientists agreed that climate change at the global level is irretrievable over a shorter period of time. Climate change requires global policy changes and sustainable agricultural practices for a longer duration of time to mitigate and reverse the ecological impairment. Several research studies have revealed that global climate change can have adverse influence on the grain yield of cereal crops produced across the world. Crop production is significantly negatively affected due to climate change (Hansen et al. 2010). The rise in air temperature has caused an enhancement of the respiration rate in crop plants and a subsequent upsurge in the carbon metabolism process; ultimately, this leads to a reduction in crop yields at local, regional, and global levels (Zhao and Fitzgerald 2013; Waleed et al. 2022; Ullah et al. 2022). Heat stress due to climate change could decrease the rice yield by between 10 and 15% that can result in an enhancement of the marketing price, ranging from 32 to 37%. Using historical weather data for the period from 1999 to 2007, the crop growth simulation model projected for Malaysia that a rise in 2 °C temperature could cause a reduction of rice production by 0.36 t ha^{-1}, which could result in an enormous economic loss (Wang et al. 2018; Mubeen et al. 2021). In a similar study, simulated results indicated that the grain yield of maize in Malawi will be decreased by 14% by the middle of this century and 33% at the end of this century due to heat stress resulting from climate change (Li et al. 2014b; Ahmad et al. 2021; Dawar et al. 2021; Ali et al. 2021). Likewise, in northeast areas of the China, global heating modeling predicted that an extreme temperature increase by 1.32 °C would result in a reduction of maize production of approximately 35% by the middle of the century when compared with the production obtained in 2008. In the United States, without adaptation strategies, climate change has resulted in an average 2.50% reduction in the maize yield from 1970 to 1999; rainfall modeling projected that at the end of this century, maize production can be decreased more, ranging from 20 to 50% under different RCPs and global climate models (Leng and Huang 2017).

4 Global Climate Change Impact on Quality

Climate change has a significant effect on nutrition quality (Asseng et al. 2019). Enhancing greenhouse gases, particularly CO_2 concentration, has caused the reduction of contents of zinc and iron in cereal crops and legume crops. Malnutrition is a serious problem due to climate change across the world. Climate change has significantly influenced on the antioxidant activity of all type of crops (Mattos et al. 2014; Bukhari et al. 2021). For instance, air temperature is considered to be the utmost

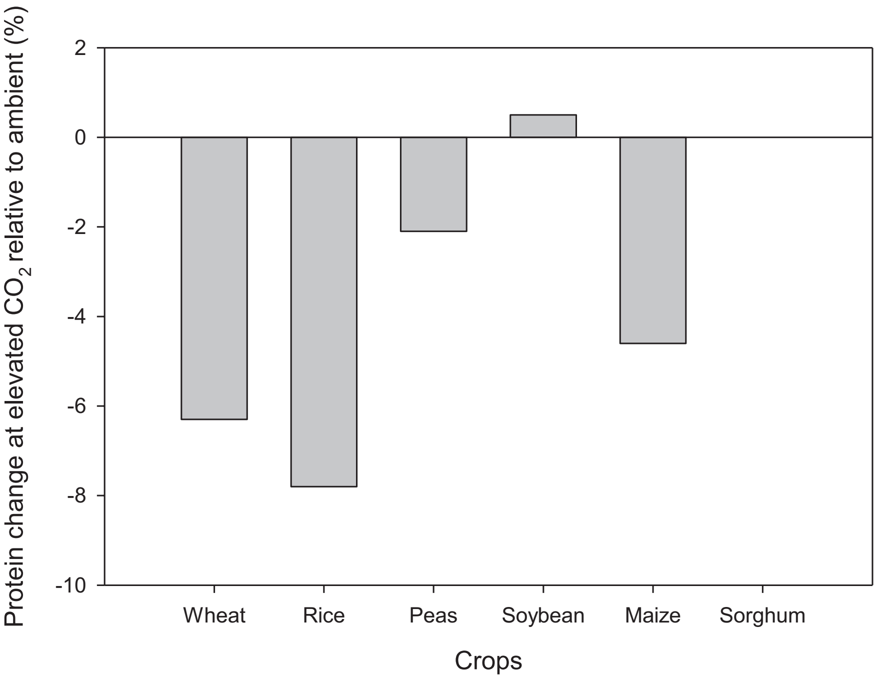

Fig. 1 Changes in protein concentration for different C_3 grasses and legumes as well as C_4 grasses at elevated CO_2 relative to ambient CO_2. (Modified after Myers et al. 2014)

significant factor, which can influence on antioxidant activity in crops, vegetables, and fruits. Higher temperature stress has been linked to a reduction of vitamin levels in all type of fruits, vegetable crops, and agronomic crops under changing climatic conditions (McKeown et al. 2006). Raised levels of carbon dioxide reduced the inclusive minerals contents of the crop plants by approximately 8%. At the same time, raised levels of carbon dioxide have caused more enhancements in the ratio of the solvable carbohydrates, such as starch and sugars, to proteins. Climate change caused thermal stress which resulted in a reduction of minerals such as zinc and iron in wheat, maize, rice, and soybean grains. These studied crops were fully-grown in an open atmosphere (free air carbon dioxide enrichment; FACE) experiments comprising the level of carbon dioxide, which might be increased by the middle of this century (Myer et al. 2014). Climate change reduced the period, as well as the contents, of protein accumulations (Fig. 1). The composition of accumulated proteins was also changed under the thermal stress as a result of variations in the quantity of whole nitrogen assimilated in the period of grain-filling phase of wheat crops (Stone et al. 1997). Protein fractions in grains, particularly albumins as well as globulins, were negatively affected due to higher temperature stress condition in lentil crops. In soybean crop, higher temperature stress, such as 35 °C in the period of seed filling, reduced oil content to 2.6%, in comparison to those grains from the plants, which were exposed to 29 °C air temperature (Sehgal et al. 2018).

5 United Nations Framework on Climate Change

The main influence on biodiversity is climate change. The biologists regarding climate change require awareness about climate policy as well as relevance of their work to imperative policy levers for climate change (Hickmann et al. 2021). As a result, conservation of the biodiversity might need aggressive measurements to control climatic changes; moreover, it is also significant for biologists of climatic changes to make awareness of accessible technologies for coping climate change as well as their restraints (Krantz 2021).

The global mechanism for counterbalance and control of climate change is the United Nations Framework Convention on Climate Change (UNFCCC). The agreement was endorsed through a comprehensive agreement between both developed and developing nations (also involving the USA). "Prevent dangerous human interference in the climate system" is the main objective of UNFCCC. Attaining this objective is contentious, despite the wide-ranging global agreement behind the convention (Ma et al. 2021; UNFCCC 2021). In 1992, UNFCCC was agreed at the "UN Conference on Environment & Development," which constitutes a foundational climate treaty; it has also offered a stage for the development of subsequent global climate treaties. The initial set of intercontinental directions designed for the implementation of the UNFCCC is the Kyoto Protocol, named after the city in Japan where the protocol was negotiated. The Kyoto Protocol was ratified in February 2005 after it was signed by Russia. The USA has repudiated to approve Kyoto Protocol, exit being major producer of GHGs outside of protocol formed to comprehend problem (Murgan 2021).

UNFCCC knows the reputation of biotic systems for assessment that at what time the climate change should be completely controlled. The agreement yardstick of "dangerous interference" is determined according to three areas: impact-sustainable development, agriculture productivity, and ecosystem responses ((Kinley et al. 2021; UNFCCC 2021). The convention stated that climate change must be detained within a time frame, which permits the ecosystem to "adapt naturally" under climatic changing conditions and does not hinder sustainability (Romanak et al. 2021).

5.1 Kyoto Protocol Signatories and Emission Targets

Kyoto Protocol is the first executing agreement of UNFCCC. Although many countries have ratified UNFCCC, the United States has never endorsed the Kyoto rules. Kyoto Protocol enter into force in February 2005 with Russia's endorsement (UNFCCC 2021). Kyoto Protocol fixed targets for emissions reductions for 37 industrial nations. Kyoto emission reductions are normally lower than 10% against 1990 levels, but the agreement received wide-ranging endorsement (184 nations have endorsed) deliver significant international impetus for achievement with regard to climate change (Miyamoto and Takeuchi 2019).

In the Kyoto Protocol, climate change assessment is based on a comparatively modest reduction in the emission of greenhouse gases, which established an average goal of 5% less than concentrations of GHGs in 1990 for advanced countries across the world. This protocol does not set any GHG reductions for developing nations, because it follows a main principle that the well-established advanced countries, which are the main contributors in terms of GHG emissions, must come forward for the reduction of emissions in their countries (UNFCCC 2021). Nevertheless, rapidly emerging economies, for example, China, Japan, and India, will have an enormous influence on emission of greenhouse gases in the coming decades. The absence of developing nation obligations is the reason why the United States declined to indorse the Kyoto Protocol, which is a significant hurdle for fighting a war against climate change at the regional and global level (Wang et al. 2019a).

The Framework Agreement about climatic variability sets a principle that the changes in climatic conditions is a serious issue for the entire world, that action may not delay upon the steadfastness of the scientifically based uncertainties, that advanced industrialized states must come forward to tackle climate change, and that they must make compensation payments to the economically poor countries for any supplementary charges experienced in implementing the actions due under the convention (Kumar et al. 2021). The Convention lacks compulsory policy promises which reveal that developed nations must have as a goal a reduction in the emission of greenhouse gases up to the GHG concentrations at 1990 levels. It launches a stronger quick process through which countries should be serious in submission of reports on their related policies as well as predictions and regular meetings to assess developments and if compulsory modify promises, and Convention will enter into force with uncommon quickness (UNFCCC 2021).

5.2 A History of Negotiations on Climate Change

At the global level, an agreement on the environment was established due to UNFCCC, the main objective of which was to fight against "dangerous human interference with the climate system," in part through an alleviation of GHG concentration in the atmosphere (UNFCCC 2021). The Convention was signed by 154 developed and developing countries at the United Nations Conference on Environment and Development (UNCED), which was previously known as the Earth Summit. This took place at Rio de Janeiro in Brazil in 1992 (Table 3). The UN conferences about climate change are held on a yearly basis under the framework of UNFCCC. They are considered to be a formal summit of UNFCCC parties (Conference of Parties, COP). The main objective of COP is to have an assessment of the progress with relation to climate change, and it began in the middle of the 1990s. Its aim was to discuss the Kyoto Protocol, aiming to establish lawfully binding commitments for the industrialized advanced countries to reduce their GHG emissions. The foremost UN Climate Change Conference was held at Berlin, Germany, in 1995. Beginning in 2005, the United Nations conferences about

Table 3 History of framework on climate change

1992	United Nations Framework Convention on Climate Change (UNFCCC) adopted (effective from 1994)
1997	Kyoto Protocol adopted (COP3) (effective from 2005) [Note] Not ratified by USA
2009	Copenhagen Accord (COP15); COP took note of the listing of emission reduction targets and actions up to 2020 of developed countries and developing countries (COP decision not reached)
2010	Cancun Agreements (COP16); emission reduction targets submitted by each country organized into UN documents
2011	Durban Platform (COP17); ad hoc working group (ADP) was established to develop a new framework applicable to all parties
2012	Doha Climate Gateway (COP18); established the second commitment period of the Kyoto Protocol
2013	Warsaw decision (COP19); the timing of the submission of emission reduction targets from 2020 (intended nationally determined contributions: INDC) was determined
2014	Lima Call for Climate Action (COP20); contents of information to be provided when submitting INDC were agreed upon and elements for a draft negotiating text for framework were elaborated
2015	Paris Agreement adopted (COP21) (entered into force on November 4, 2016); agreement reached for the first time where all parties participate in taking concrete measures against climate change
2016	Marrakech Climate Action (COP22); the first meeting of the parties to the Paris Agreement (CMA1). The purpose of the conference was to discuss and implement plans about combatting climate change and to [demonstrate] to the world that the implementation of the Paris Agreement is underway
2017	Bonn Climate Action (COP23); discuss and implement plans about combating climate change, including the details of how the Paris Agreement will work after it enters into force in 2020
2018	Katowice Climate Action (COP24); the conference agreed on rules to implement the Paris Agreement, which came into force, that is to say the rulebook on how governments will measure, and report on their emission-cutting efforts
2019	Madrid Climate Action (COP25); the conference incorporated the 25th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), the 15th meeting of the parties to the Kyoto Protocol (CMP15), and the second meeting of the parties to the Paris Agreement (CMA2)
2021	Glasgow Climate Pact (COP26); The pact was the first climate deal to explicitly commit to reducing the use of coal. It included wording that encouraged more urgent greenhouse gas emissions cuts and promised more climate finance for developing countries to adapt to climate impacts
2022	Sharm el-Sheikh Climate Action (COP27); For the first time, a loss and damage fund were agreed upon at the conference, which was seen as a great achievement. The loss and damage fund are an agreement that provides financing to nations that are the most susceptible to and affected by climate change. This was a huge breakthrough that will benefit underdeveloped countries suffering the most severe consequences. There was no promise to phase out fossil fuels. Countries had failed to abandon fossil fuels. Despite their emphasis on “low emission energy,” this remains a source of greenhouse gas emissions
2023	Dubai Climate Action (COP28); The first Global Stocktake of the implementation of the Paris Agreement will conclude at COP28. Each stocktake is a two-year process that happens every five years, with the aim of assessing the world’s collective progress towards achieving its climate goals. The first Global Stocktake takes place at the mid-point in the implementation of the 2030 Agenda for Sustainable Development and its SDGs, including Goal 13

climate change have also served as “Conference of Parties Serving as Meeting of Parties to Kyoto Protocol” (CMP); this also gives opportunity to parties to the convention (which are not agreed within the Kyoto Protocol) to join in the protocol-connected meeting as observer countries. From 2011 to 2015, the main objective of meetings was for the negotiation of the Paris Agreement as a part of the Durban platform, which formed a universal path toward climate action at the global level. Subsequent to the progressively extensive agreement in the scientific community that GHGs are a noteworthy carrier of climatic changes across the world (IPCC 2013), as well as being pressured through a rising public consciousness of the associated effects of climate change, several global discussions have been carried out in the previous three decades for the reduction of GHG emissions. The early efforts to counteract climate change have focused on the diminution of greenhouse gas emission from developed countries in this manuscript, which ultimately became the Annex 1 group of the Kyoto Protocol. Nevertheless, subsequent to the entering into force of the Paris Agreement (UNFCCC 2021), more than 180 developed and developing countries agreed to make on a nationally determined contributions to the goal of keeping the global temperature rise at less than 2 °C and taking measures to limit the global average temperature rise to just 1.5 °C. A total of 27 countries of the European Union and the United Kingdom have set legitimately binding promises to become carbon-neutral economies by the middle of the twenty-first century. The European Commission has proposed a lessening of 13.3% in GHGs emissions, in comparison with the 1990 level, which will be gradually attained up till 2030 (European Commission 2021).

In 1994, UNFCCC was established, and 197 developing and developed countries ratified this. With respect to structure as well as content, UNFCCC is designed as framework convention, such as the “Vienna Convention for Protection of Ozone Layer & Convention.” The transition of the framework is principally carried out by the United Nations (Fig. 2). Multifaceted accords are now normally established by a proper procedure that commences with a “framework” treaty, where all participating developed and developing countries recognize the existence of any issue or disturbance and are obligated to undertake supportive action with regard to one another, deprived of undertaking the substantive commitments. As knowledge as well as agreement raise with the help of this framework, the agreement is complemented through a succession of protocols and modifications gradually imposing additional precise as well as more strict commitments on agreement parties.” Vienna Convention could not direct execute reins on the ozone diminishing elements nevertheless in its place formed a procedure for assortment of variety of evidence along with negotiation of a future treaty (Montreal Protocol on Substances which Reduce Ozone Layer) comprising explicit emissions limits. Correspondingly, the UNFCCC comprises some definite requirements, as well as, especially, no enforceable prerequisite for the participants to reduce emissions of greenhouse gases (UNFCCC 2021). The parties declare their main objective of alleviating the concentration of greenhouse gases in the atmosphere at a level that would avert hazardous anthropogenetic interfering with climate systems; in addition, industrialized advanced countries agree to the adaptation of state policies for the alleviation of climate change in line with setting

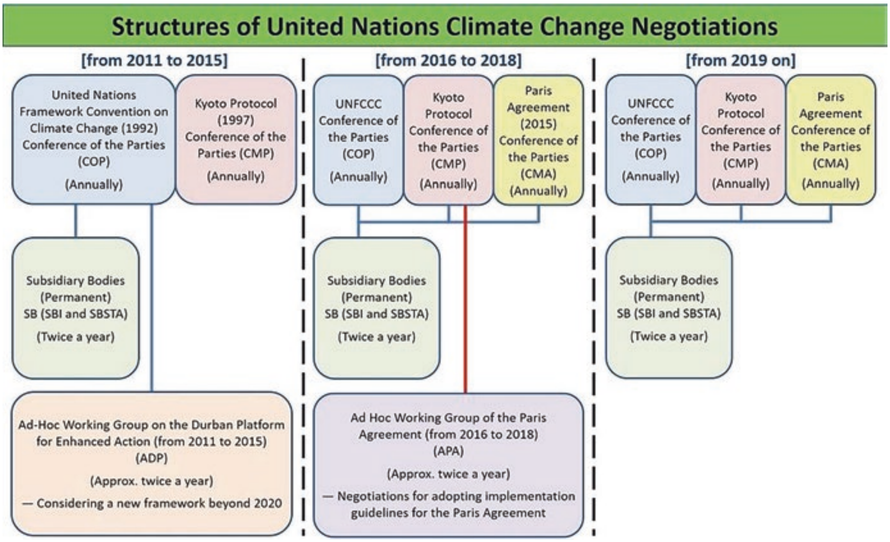

Fig. 2 Transition of the frameworks on climate change

goal of return to their 1990 level of anthropogenic emission of greenhouse gases. The UNFCCC was developed with the main goal of instigating and sustaining a process for the upcoming decade's scenarios, as well as highly comprehensive treaties about how to tackle climate change at local, regional, and global levels (UNFCCC 2021). Last COP27 under UNFCCC was held from 6th to 20th November, 2022 in Sharm El Sheikh, Egypt. At the meeting, a loss and damage fund were approved for the first time, which was hailed as a major accomplishment. An arrangement called the loss and damage fund gives money to countries that are most vulnerable to and impacted by climate change. This was a significant advancement that would help developing nations that are now facing the worst effects. However, no commitment was made to phase out fossil fuels. Fossil fuels had not been abandoned by nations. Even though they place a lot of focus on "low emission energy," this still produces greenhouse gas emissions. Next COP28 under UNFCCC will be held from November 30th until December 12th, 2023 at the Expo City, Dubai. The goals of the COP28 include: 1) to ensure that youth views and suggestions are completely combined into global climate policy making and dialogues. 2) to build youth skills, capacity, knowledge, and networks, particularly in the most impacted countries, to engage in climate processes. Some of utmost noteworthy means that UNFCCC inclined, as well as continues to shape, worldwide discussions are mentioned in following.

5.3 *Climate Change International Framework: Outline*

The global community holds the worldwide climate change task. Three main tools that encouraged global strategies to mitigate GHG emissions through adaptation to adverse influences resulting from uncertain climates are discussed below.

(A) *UN Framework Convention on Climate Change*

- Determination: Stabilize concentrations of GHGs in atmosphere at a quantity that would stop hazardous interaction with climate system
- Recognized in May 1992, operative since March 1994. Parties in convention: 197
- Differences among developed and developing states ("common but differentiated responsibilities and respective capabilities")
  - Annexure-I Parties: Parties stated with GHG decrease targets
  - Non-Annexure-I Parties: Developing states not declared with GHG decrease targets
  - Annexure-II Parties: States (developed) having responsibility to support financially for accomplishment of responsibilities under Convention by non-Annexure-I Parties
- At COP1, responsibilities on Annexure-I Parties were reinforced (Berlin Mandate).

(B) *Kyoto Protocol*

- Emission decrease responsibility
- Responsibility obligatory on Annexure-I Parties to decrease GHG emissions up to a definite level in a quantified time period vis-à-vis no decrease responsibility on non-Annexure-I Parties
  - First obligation time frame (from 2008 to 2012): Japan 6%, the United States 7%, and EU 8%
  - Second obligation time frame (from 2013 to 2020): EU 20%, Japan, not participated.
- Recognized in Kyoto in December 1997, operative since February 2005. Parties: 192
- The United States signed however not endorsed Protocol and Canada retreat in December 2012

(C) *Paris Agreement*

- At COP21 in December 2015, Paris Agreement was approved as agenda valid for all parties for the first time. Agreement approved on November 4, 2016.
- Numerous agendas about climate change have transited pre- and post-Paris Agreement.

6 Conclusions

Climate change has affected every sector across the world. Mitigation and adaptation strategies are each very necessary against climate change. Global framework can play a significant role for a reduction in the negative impact of climate change and the lessening of greenhouse gases. Proper implementation of decisions was taken at the United Nations Climate Change Conference in Paris, COP21, at which the participating countries agreed that the mobilization of stronger and more ambitious climate action is immediately mandatory for the achievement of all goals of the Paris Agreement. Accomplishment in terms of the reduction in greenhouse gas emissions must be coming from governments, cities, regions, businesses, and investors. Everybody should take their responsibility in terms of the successful implementation of the Paris Agreement.

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Conceptual Elucidation of Climate Change for Developing Countries

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Abstract The word climate change is being used as a buzz word in developing countries, and yet its conceptual understanding is not very clear to common people in various parts of the world even among educated communities. To clarify the understanding about climate change, it is being elucidated here: various indicators

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_2

to know about climate change, its causes, and link with several extreme weather events that have triggered the whole world to sit together and ponder over to find solutions to deal with this menace. The conference of parties (COPs) is happening regularly, and day by day, each country is eagerly trying to increase their focus of nationally determined contributions toward greenhouse gases. Climate change and climate variability are haphazardly used by various organizations and media while we have tried to present the conceptual elucidation of climate change in a simpler and easy to understand way.

Keywords Temperature rise · Glacier melting · Vulnerability · Adaptation · Reducing GHG emissions · Cost-benefit analysis

1 Introduction

The aggregate of long-term atmospheric conditions is termed as climate in contrast to the current conditions of atmosphere at any particular place and time, which represent the weather and can be differentiated mainly and commonly on the basis of prevailing duration of atmospheric conditions. Changing climate is the result of a change in the mean temperatures of our surroundings, and that is linked with the industrial development of certain parts of the world while blamed mainly on domestic, agricultural, energy, and transportation systems and all activities on planet due to anthropogenic reasons. Population has been blamed as the key contributor or deriving force as per the recent reports of intergovernmental panel on climate change expert's production of assessment report (AR6). People's usage of gas, oil, and wood in the form of coal at all places like residences, workplaces, and transportation has contributed in swift and severe variability in climate. Various anthropogenic activitiies contribute to global warming thus making it the core reason in warming our surroundings. When humans burn all kinds of fossil fuels, greenhouse gases (GHGs) are released, primarily carbon dioxide (CO_2), methane, chlorofluorocarbon, water vapors, and carbon monoxide. The energy from the sun is absorbed by these gases and particles allowing the earth's natural temperature to increase. From 1906 to 2005, global average temperatures have been risen by 0.6–0.9 °C and are further expected to rise to 4 °C, while efforts are being made to contain this rise in temperature to maximum 1.5 °C.

2 Major Indicators of Climate Change

(i) Rise in temperatures
(ii) Heavy precipitation
(iii) Melting of glaciers
(iv) Drought

(v) Decreasing snow fall and increasing sea level
(vi) Greenhouse effect

2.1 Rise in Temperatures

The average temperature of atmosphere and oceanic water is increasing day by day due to which the intensity and frequency of droughts, floods, plagues, and heat waves are growing. Oceans occupy over 70% of the earth's surface, and you can understand how very much warmer temperatures of water and air of the oceans may badly affect the climate system. More floods, storms, disasters, earthquakes, hurricanes, and extreme precipitation events are predicted. Severe cyclones, floods, storms, and disasters may become stronger and more frequent as a result of the increased temperature of air and water present in ocean, which produces more heat (Ali et al. 2021; Rehman et al. 2021; Mehmood et al. 2021; Mubeen et al. 2021; Hussain et al. 2022a, b).

2.2 Heavy Precipitation

In recent years, a higher percentage of precipitation in developing countries such as Pakistan, Nepal, Sri Lanka, Bangladesh, India, and many other has come in the form of intense single-day events. These areas are characterized by heavy rainfall for a short time period. Since 1990, eight of the top ten years for heavy one-day precipitation have been recorded. In September, the country India saw 89 severely heavy rain events, compared to 61 in the same month last year (2020), 59 in 2019, 44 in 2018, and 29 in 2017. In India, the failure of the monsoon in the year 2002 considerably hindered the economic growth (Stern and Stern 2007; Amin et al. 2018a, b; Ali et al. 2019; Hussain et al. 2020a, b; Mubeen et al. 2020; Hashmi et al. 2020; Zamin et al. 2020).

2.3 Melting of Glaciers

According to the current study, glacial melting has increased during the previous three decades. This ice loss has now exceeded 335 billion tons yearly, accounting for 30% of the current pace of ocean enlargement. The following are the primary impacts of deglaciation. Since 1961, glacier melting has resulted to a 2.7 cm sea level increase. However, the world's largest glaciers have adequate ice (approximately 170,000 cubic kilometers) to increase ocean levels by approximately half a meter (Awais et al. 2018; Amin et al. 2018c, Nasim et al. 2018a, b; Shahzad et al. 2018).

2.4 Drought

Drought has a variety of impacts on the environment. Water is very essential element for plants, animals, humans, and even for all types of creatures present on earth. Sometimes drought and famine are often only temporary, and their environmental condition and food supplies return to normal situation when such drastic conditions become favorable. But sometimes drought's impact on the environment and all living things like plants, animals, and humans can last a long time, maybe forever. For example, during the 3 years from 1997 to 2000, El Nino and La Nina were major proceedings that occurred in Kenya and economy lost up to 22% of its entire country GDP owing to floods and drought (Biemans et al. 2006; Amin et al. 2017a, b; Abbas et al. 2017; Awais et al. 2017a, b; Mirza et al. 2017; Ahmad et al. 2017; Fahad et al. 2018).

Some examples of environmental consequences are as follows:

- More wildfires
- Migration of wildlife
- Low soil quality
- Fish and wildlife habitat destruction
- Wetland depletion

2.5 Decreasing Snow Fall and Rising Sea Level

The Arctic sea ice cover increases within winter when there is less daylight duration and has fewer sunshine hours and contracts in the summer when days are longer and weather is warmer, reaching its lowest point or minimum value in September. Since the turn of century, sea level is rising gradually on yearly basis, glaciers melt faster, sea temperatures increase, imposing oceans to inflate, and rising water levels are enhanced in current years. You can image the impact on over 40% of the population who live in a densely populated and urbanized coastal region. Don't forget that world's ten most populous major cities are situated near a coastline (Nasim et al. 2017; Awais et al. 2017a, b).

2.6 Greenhouse Effect

The earth takes nearly all-natural heat and light energy from the sun and then radiates a large portion of this sun energy back into space. However, some specific gases present in the atmosphere termed as greenhouse gases absorb a part of the emitted energy and retain it in atmosphere. Although the greenhouse effect naturally occurs, human activities have significantly enhanced the quantity of all greenhouse gases into the atmosphere, which causes the Earth to be hotter and hotter. When fossil

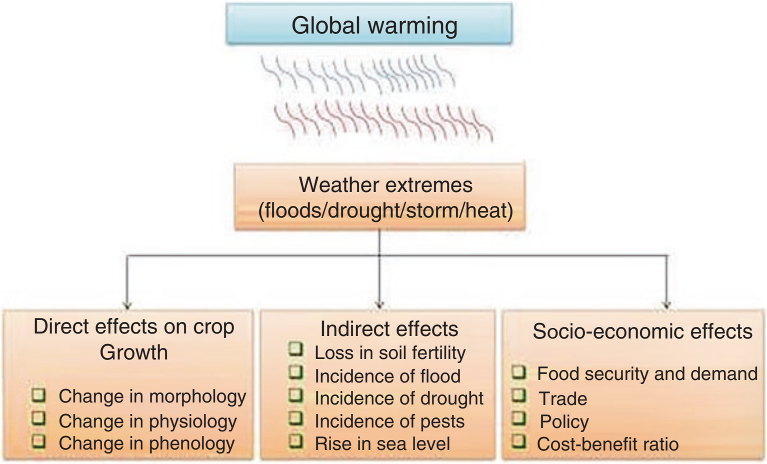

Fig. 1 Direct and indirect impacts of climate on crop growth, soil health, and social life

fuels like coal, gas, and oil are used in burning process, a huge quantity of carbon dioxide is released into environment resulting in warmer earth's environment due to which climate change is happening.

2.6.1 Impact of Climate Change on Different Sectors

Temperature increase because of weather trade may specially regulate bio-bodily relationships for crops/cattle//forests and fisheries inclusive of shortening of the growing durations, converting the species styles, increasing thermal and moisture stresses, converting water necessities, changing soil traits, and growing threat of pests and diseases (Fig. 1). The outcomes of weather exchange on agriculture and other resources can also range across the numerous agro-ecological zones. Rise in temperature should enhance the method of deglaciation by using affective water sources on which the United States depends for agriculture and electricity production within the dry western mountain regions. Mountainous regions are already under extreme pressure because of diverse anthropogenic activities (Nasim 2007, 2010; Shahid et al. 2014; Amin et al. 2015; Nasim et al. 2016a, b, c; Mubeen et al. 2016).

2.6.2 Forest Sector

Climate change influence the loss of biodiversity and woodland of north regions. Predicted precipitation has affected forests inside watersheds. The frequency of fire in forest increases because of the elevated heat and rainfall, which are reason of harm to forest revival and new plantation.

2.6.3 Pest and Diseases

Climate change threats the proliferation of diseases and pests that negatively influenced the community. Pest disease and insects proliferate in high rainfall situations like wheat rust, root rot disease, and bollworms of cotton.

2.6.4 Water Resources

Uncertain and erratic rainfall pattern has effect on arid and hyper-arid regions. Glaciers all around the world are receding rapidly because of global warming. Glaciers have severe implications for sustainable water supply. In the next three decades, glacial melt in the Himalayas is expected to increase flooding. This can be accompanied by decrease in river flows.

2.6.5 Livestock Sector

Weather trade influences cattle productivity due to increase in temperature that imposes physiological stress on productivity of animals, climate-related sickness epidemics, reduced productiveness of fodder, decreased palatability and fine forages, and elevated water necessities of animals.

2.6.6 Effect of Climate Changes on Human and Natural Environment

Recent climatic changes and variations are emerging to have an impact on many natural and human systems (Fig. 2). Moreover, research that is now available indicates that the results have not yet developed into patterns.

- Mountainous areas are particularly at risk from glacial lake outburst floods brought on by melting of glaciers. Governmental organizations have started building dams and drainage systems in some areas as a response.
- In Africa's Sahelian area, warmer and drier circumstances have resulted in a shorter growing season, which has harmed agriculture. Longer dry seasons and more unpredictable rainfall are forcing adaptation strategies in southern Africa.
- Rise in sea level and human development are both contributing to the destruction of coastal wetlands and mangroves, as well as increased damage caused by coastal flooding (Hansen and Cramer 2015).

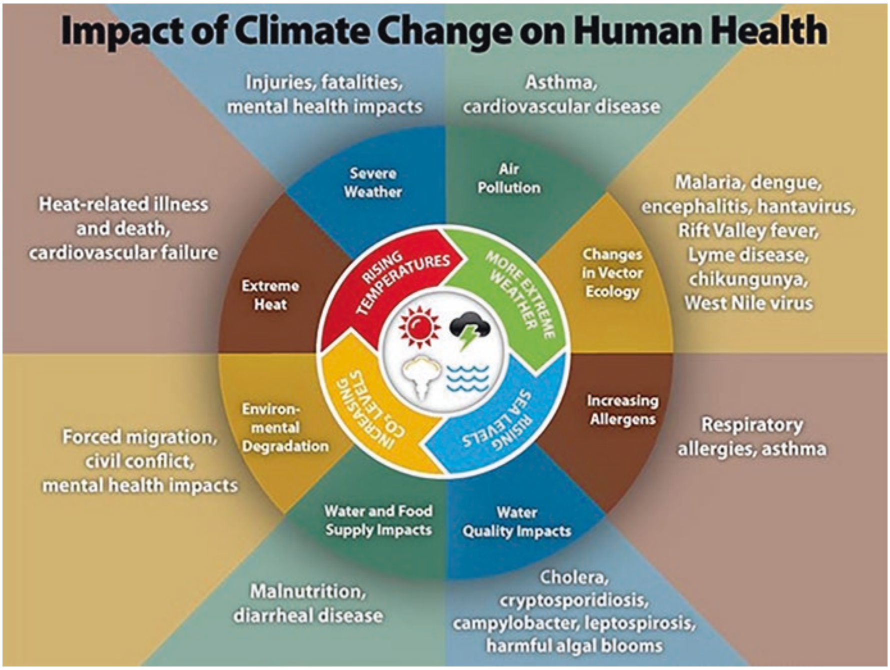

Fig. 2 Hazardous effect of changing climate change on human

3 Limiting Factors That Intensify Climate Risks in the Developing Countries

The globe at present is 1.2 °C hotter than it absolutely was within the1900s—as the carbon dioxide's quantity inside the atmosphere has increased up to 50%.

Global climate change may be split in two classes:

(i) Threats related to the adaptation to a lesser carbon economy
(ii) Threats associated to the visible effects of worldwide climate change

4 Effect of Global Climate Change on Developing Countries

Global climate change influences each country and might have calamitous reactions on society. Third world countries are the foremost wedged by global climate change and therefore less able to bear its negative outcomes. According to the World Health Organization, up to 2030, global climate change is predicted to put up around 250,000 extra deaths per annum, due to diseases, malaria, diarrhea, and heat stress.

4.1 Effect of Global Climate Change in Pakistan

4.1.1 Observed Changes in Climate (Meteorological Facts)

The World Meteorological Organization reported that there are number of changes in climate conditions (meteorological facts). Some observed changes in the climate of Pakistan in the recent years are as follows:

I. Temperature has increased at a rate faster than in other parts of the world.
II. Rainfall has not increased in recent years, but there is an increase in average wind speed.
III. Climate changes have caused increase in freshwater consumption.
IV. There is a problem of shifting agricultural and living zones.

4.1.2 Pakistan Meteorological Department Observations

According to the observations carried out by Pakistan Meteorological Department, a general increase in temperature above normal has been observed over country since monsoon season. The trend of increasing air temperature throughout the globe is very much evident. This may be attributed to the effects of global warming. The consequences of increasing global temperatures are serious such as inundation of coastal areas from sea level rise and in Pakistan started experiencing climate changes about 50 years ago. During the past half century, surface air temperatures have risen by 0.5 °C in the winter (December to February) and autumn (October to November) season and 0.4 °C in the summer (March to May) season. Precipitation has intensified during the monsoon season with a mean increase of 22%. Droughts have become more frequent and severe in the arid and semiarid districts of Baluchistan, northern Punjab, and Sindh increased incidence and severity of thrilling weather proceedings.

4.1.3 Impacts of Climate Change

Economic Impacts

The Intergovernmental Panel on climate change (IPCC) 5th Assessment Report (AR5) for the area of Asia considered that the responsiveness of agriculture-reliant economies (like Pakistan) toward climate change emerge from their definite geographical drifts, demographic elements, and absence of accommodative capability that once taken along verify the global climate change liability of country. Because of utmost weather and unsure economic impacts, rural communities in Pakistan are move toward cities and according to an estimate as about 20 million rural people migrated until 2010. Similarly, the water available/person is forecasted to lessen to an inexcusable level.

4.2 Effect of Global Climate Change in India

4.2.1 Factors That Influence the Climate of India

Latitudinal Location

The Indian climate seems like of equatorial country. The principal land of Asian nation expands within the middle of 8° north to 37° north. Areas in the south of the Tropic of Cancer are in equatorial area and thus obtain lesser solar insolation. Temperature of summer season is extreme, and winter temperatures are moderate in most of the regions. The northern elements on the opposite hand belong the nice and cozy climatic zone. They receive relatively less star insolation. However, summer season is quite hot to north Indian region as a result of hot native winds being called "lu." Winter is terribly cold because of cold waves driven by the disturbances in the west.

Distance from the Ocean

Coastal areas have mediocre climate, whereas interior locations have utmost or continental climate. The monsoon's winds initially reach the coastal areas and thus give smart quantity of precipitation.

Monsoon Winds and Indian Climate

The most dominating issue of the Indian climate is that the "monsoon winds," which drive unexpected monsoons onset (unexpected burst). The absolute turnaround of winds of the monsoon leads to a few abrupt amendments within seasons. The hard summer season instantaneously provide way to season of rain or monsoon. The Bay of Bengal and the south-west monsoons coming through the Arabian sea led precipitations to the whole country. The winter season monsoon of the north-eastern causes a lot of precipitation except on the Coromandel coast (TN coast) once obtaining moisture from the Bay of Bengal.

4.3 Effect of Global Climate Change in India

There are some results given below:

4.3.1 Economic Impact

India has the world's top social value of carbon. A report by the London-based world think factory Overseas Development Institute found that India could drop anywhere around 3–10% of its gross domestic product in a year by the year 2100, and its rate of poverty could increase by 3.5% in 2040 because of global climate change.

4.3.2 Agriculture

India's climate change can have unreasonable impact on 400 million population that equal to poor people. This is result of numerous number of people relying on natural resources for their financial benefit, shelter and food. More than 56% of individuals in India has a profession related to agriculture, whereas several others obtain their livelihood in coastal regions.

4.3.3 Health Impacts

Pollution in air throwbacks daylight and irrigation, cools down the air through evaporation process, and has prevented global climate change since 1970. These two elements however increase the heat waves' impact and resulted in increased mortality rate.

5 Adaptation to Future Climate Change

5.1 Developing Countries Vulnerability to Climate Change

5.1.1 Vulnerability to Climate Change

Vulnerability to climate change is that how much an environment can be bearable and incapable to survive with unfavorable conditions like extremity of climate and irregularity in climate (Fig. 3). Climate change has affected world countries, but developing ones are more vulnerable than developed countries.

Due to inadequate mitigation and adaptation, it is difficult to control over the increasing climate change. Climate change could make adverse situation of poverty and lessen the chances for having sustainable environment. It will make hard for the people of developing countries to come out of the poverty.

Climate change mostly affects the economic growth of developing countries. Planning of reduction in greenhouse gases in developed countries has been promoted to minimize the impact of climate change. By using technology, developed countries should also make strategies to mitigate the impact of climate on developing countries (Fellmann 2012).

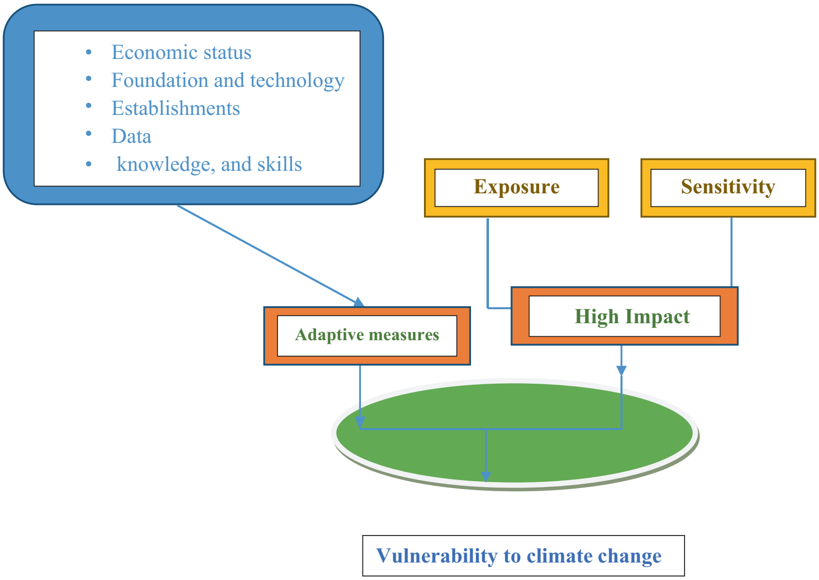

Fig. 3 Flowchart for vulnerability to climate change

5.1.2 Sustainable Agriculture and Climate Change

By boosting adaptive capability and resilience, sustainable development can lessen susceptibility to climate change. Now, few programs for promoting sustainability expressively address either adjusting to the effects of climate change or building adaptive capability. Climate change, on the other hand, is quite likely to reduce the speed of progress toward sustainable development, either directly via greater vulnerability to unfavorable impacts or indirectly by eroding adaptability. This fact is well proven in the portions of this report's sectoral and regional chapters that address the implications for sustainable development (Lough and Hobday 2011).

5.2 Climate Change Policies for Developing Countries

The European union should realize to take steps for mitigation and adaptation for poor countries so that poverty and hunger could be controlled to some extent. Analysis for climate change vulnerability is necessary for planning suitable policies (Fulco Ludwig 2007).

- Climate change policies should be different for different countries according to their geographical location and economic status.
- There should be separate plans for rapidly developing countries, which includes Brazil, China, Indonesia, etc.

- There should be adaptative strategies for least developing countries.
- In least developing countries, the emission of hazardous gases is low as compared to fast developing countries; therefore, mitigation strategies will not work effectively.
- Developed countries have excess resources and access to modern energy, and these countries consume highest rate of energy and are cause of greenhouse gases.

6 Climate Change Mitigation Strategies Adopted by Pakistan Government

(Source: Report Ministry of Climate Change 2019–2020)

6.1 Forestry

Country land of 5.01% is under forest, making 4.51million hectares of the total area of country. The forest industry accounts for 0.41% of GDP. The government has made several steps to enhance the amount of forest cover.

6.2 The Major Activities Are Given as Follows

6.2.1 Ten Billion Tree Tsunami Program (TBTTP)

Primary goal of this initiative is to fight with negative impacts of global warming. Under umbrella of this project, all provinces comprising GB and AJK get provincial financial share. Federal and provincial forestry department also participated across the country. Farmers and students all have been dynamically involved in the mega tree plantation project. TBTTP was given Rs 7.5 B in PSDP from 2019 to 2020, in which 6.0 B has been distributed to provinces.

6.2.2 Seasonal Tree Planting Campaigns

Yearly programs to plant seasonal trees are held to increase the nation's tree cover. Throughout the year, planting efforts were carried out by government agencies as well as businesses, NGOs, and groups serving defense industry. The current situation in relation to the tree planting goals is as follows:

6.2.3 Seasonal Tree Planting Campaigns

Every year, seasonal tree planting programs are performed in attempt to increase the country's tree cover. Throughout the year, planting operations were carried out by government agencies, commercial sector groups, defense organizations, and non-governmental organizations.

6.2.4 Clean Green Pakistan Index

The Prime Minister introduced the Clean Green Pakistan Index (CGPI) to establish a system for improving public services offered by local governments for five components of Clean Green Pakistan (CGPI). Hygiene, waste management, water, and plantation are the five pillars of the Clean Green Pakistan Program, and each is given equal weight. The ultimate Clean Green Pakistan Index will be determined by adding the scores for each of the five pillars individually. For the CGPI rankings of cities, more than 35 indicators were used. CGPI is based on information provided by municipal committees in 19 major cities. City councils and administration work together to generate data monthly at district level of country. The CGPI has inaugurated as a pilot project in 13 cities of Punjab, consisting of Attock, Gujrat, Multan, Sargodha, Muree, Bahawalpur, DG Khan, Rawalpindi, Lahore, Gujranwala, Sahiwal, Sialkot, and Faisalabad, and directed in seven cities of KPK that comprises Peshawar, Malakand, Abbottabad, Bannu, Kohat, Mardan, and Dera Ismail Khan.

6.2.5 Reducing Emissions from Deforestation and Forest Degradation (REDD+) Participation

Process of absorbing atmospheric carbon through forest resources is referred to as Reduced Emission from Deforestation and Forest Degradation (REDD+). The financial worth of standing trees rises as carbon accumulates. In carbon markets, carbon stored in forests is exchanged. Since July 2015, Pakistan has been implementing the REDD+ Readiness Preparation Proposal (R-PP) with a grant of $ 3.8 million. The World Bank's Forest Carbon Partnership Facility (FCPF) also approved Pakistan grant after a competitive procedure. Credentials for the four aspects necessary to complete the REDD+ ready segment were prepared by international and national consultants. Meanwhile, the FCPF provided an extra grant of $4.01 million in 2018 to continue to assist Pakistan's preparation efforts through June 2020.On February 6, 2020, the 9th National Steering Committee met to further simplify the implementation process. Pakistan has submitted its Forest Reference Emission Level (FREL) to the United Nations Framework Convention on Climate Change (UNFCCC).

6.2.6 Preparation of Pakistan's National Drought Plan

The "Drought Initiative" attempts to support republics progress national action plans to increase their ability to withstand droughts. A national advisor for Pakistan has nominated by the Global Mechanism Team of the United Nations Convention to Combat Desertification (UNCCD) to draught a wide-ranging national action plan towards this goal.

6.2.7 National Biodiversity Strategy and Action Plan (NBSAP)

The National Biodiversity Strategy and Action Plan (NBSAP) was authorized in November 2018 and currently being implemented with provinces. This strategy is in line with Sustainable Development Goals (SDGs) (2030).

6.2.8 Declaration of Marine Protected Areas

Astola Island was designated Pakistan's first coastal marine area in June 2017. Churna Island and Miani Horr are two other possible areas that are in the process of being designated as Marine Protected Areas.

6.3 Measures to Protect Environment

I. *Pakistan's Fight Against Plastic Pollution Is Saving Both People and Marine Life*

The main issue with plastics is that a large fraction of production consists of things that are cost of forever after a year of manufacturing, including PET bottles for mineral water or soft drinks, toothbrushes, styrene coffee cups, children's toys, and plastic bags.

This high rate of disposal and durability is the primary cause of plastic pollution, which manifests itself in landfills and plastic patches in the oceans. Plastic goods endanger the seas, animals, human life, and ecosystem as a whole. As a result, Pakistani government passed the Regulations on the Ban on (Manufacturing, Import, Sale, Purchase, Storage, and Usage) Polythene Bags. MoCC has provided substitute bags made of cotton, jute, and other legal materials. In collaboration with the Ministry of Information and Broadcasting, the Ministry also launched an awareness campaign about the dangers of polythene bags and their substitutes.

II. *Standard Operating Procedures to Facilitate the Transit of Recyclable Materials Across International Borders*

Pakistan is a signatory to the Basel Convention on the Control of Transboundary Movements of Dangerous Wastes and their Dumping, and the MoCC is the National

Focal Point and Competent Authority for national compliance with the Convention's provisions. The articles of the Convention, which call for the regulation of garbage import, export, and transit, are binding on Pakistan. The Ministry has launched Standard Operating Procedures (SOPs) for awarding licenses to import goods under the Basel Convention in 2019 in order to facilitate transboundary fluxes of recycled content.

III. *Protecting the Ozone Layer*

The Montreal Protocol (MP) provides a phaseout of ozone depleting compounds that is implemented by the Ministry of Climate Change (ODS). In order to increase awareness among certain stakeholders, the National Ozone Unit (NOU) continued to be actively involved in a number of events. The main tasks were as follows:

(i) The HCFC import limitation for 2019 was effectively administered in accordance with Pakistan's baseline allocation of 248.11 ODP tons.
(ii) Initiated a process to seek the aid of academics to carry out research and studies in order to establish best practices for the phaseout of ODS in Pakistan. A Memorandum of Understanding on this subject has been signed by the Ministry of Climate Change, the National Ozone Unit, and the National University of Science and Technology (NUST).
(iii) Executing a campaign to raise awareness about ozone layer protection with radio spots, TV commercials, and newspaper inserts made to celebrate International Ozone Day 2019.
(iv) Launched the progression of developing legal tools to control the managing of ozone-depleting compounds in Pakistan.
(v) To examine the import numbers and utilization of the allotted import quota, FBR collected HCFC import data on a monthly basis. This assists Pakistan in maintaining compliance with laws governing the import and use of several ozone depleting substances.
(vi) The necessary steps were taken to ratify the Kigali Amendment.

IV. *Implementation of Hospital Waste Management Rules (2005)*

Pakistan Environmental Protection Agency is in charge of implementing hospital waste management regulations. Hospitals and other public healthcare services are built for community safety. Mismanagement of hospital waste causes severe attack of diseases, and waste itself is also a problem. The best method for disposing of safely and affordably waste is to separate it into "infected" and "noninfectious" wastes. The general waste can then be transported to a landfill and disposed of in an efficient manner using standard methods. The contaminated trash can be carefully managed and processed before being disposed of by burning or any other scientific procedure, with the garbage's ash then being dumped in landfills. In order to maintain hygiene, modern practice dictates that all garbage be covered at night or earlier.

6.4 Reducing GHG Emissions from Agriculture and Land Use Change

6.4.1 Background

The greenhouse gas effects are controlled by the extensive use of land and agriculture, and both of these factors contribute a lot of GHG emissions. The UN Sustainable Development Goals (SDG) sets top three goals, which are poverty, good health, and zero hunger. The climate change is also becoming a major problem for agriculture. There is 2 °C global warming rise, and it should be reduced to lower bad impacts of climate change. Therefore, a precise and comprehensive approach is needed in reducing GHG emissions (Thapa 2021). In one side, agriculture and land use are involved in GHG mitigation efforts, and on the other hand, it is contributing to GHG emission around 23% (Prudhomme et al. 2020).

6.4.2 Introduction

According to estimates, nearly half of emission of greenhouse gases is due to methane, nitrogen oxides emitted by field activities, while other half emission out of total is from deforestation and extensive land use (Wieding et al. 2020). On AFOLU releasing area, there should be reduction in emission. The loss of GHGs caused by deforestation of forests and other C-filled resources of biomass was reduced to a great extent. For this purpose, the management practices in agriculture were increased to enhance the efficacy of fertilize use, manure use, and water use efficiency (Christoph et al. 2019).

The reduction in GHG emission from AFOLU related products and reduction in food use and waste resulted in change in schemes for agri. Products and production areas (Filho and Junior 2020).

6.5 Reduction of Emission Through New Technologies

6.5.1 Better Manure Management Resulted in Lesser Emission

When animals are raised in an area that is closed, the manure is collected and disposed of. The methane and nitrous oxide are emitted from managed manure. Almost half of this emission is contributed by pigs while 15% by beef cows and over one-third by dairy cows. The environmental problems and human health issues can be managed by improving manure management.

6.5.2 Increasing Nitrogen Use Efficiency Lessen Emission

In 2010, about 1.3 Gt CO_2 *emissions were recorded by the use of fertilizer in* crops and pastures. The overall emissions were noticed from the manufacturing sites and use of nitrogen. Globally, less than half nitrogen is absorbed by crops, while the remaining is lost by ground and surface runoff. It resulted in pollution and escapes of GHGs into the air as gases. Mitigation strategies focus on changing agronomic practices. Such type of practices is difficult and expensive and that's why modifications and innovation are needed (Markets 2015).

6.5.3 Emission Reduction in Rice Management and Varieties

Approximately 10% contribution to global greenhouse gas emission from agriculture was noticed from paddy fields. This gas was emitted by methane gas utilization. The options available to include professional technical support and reduction practices offer various prospects by considering economic aspects (Su et al. 2015).

6.5.4 The Necessity of Technology and Regulations

Many options are available to mitigate GHG emission, and voluntary options are not the only options. The use of fertilizer should be encouraged, and fertilizer use efficiency should be enhanced. In India, fertilizers were coated with extracts of neem, and it reduced nitrogen emission. In less privileged areas, there should be introduction of inhibitors of methane (Padhi et al. 2018).

7 Cost-Benefit Analysis for Climate Change Adaptation

7.1 Overview

This briefing note covers key analytical processes for carrying out a cost-benefit analysis (CBA) and illustrates the role and logic of it in the evaluation of policies and programmed for addressing climate change in the agriculture sectors by using real-world examples. The note outlines the typical CBA technique but focuses on the unique implementation issues when it comes to climate change adaptation in the agriculture sectors.

1. CBA is a method and judgement-making tool that assists in the identification of solutions for the effective provision of limited financial assets. It is frequently done in relation to a project that's being considered but hasn't started yet. It also contributes to the NAP procedure by calculating the charges and profits of various climate change adaption solutions.
2. CBA is made up of a number of diagnostic phases. It is based on a set of assumptions that predict the predicted results of climate change mitigation and edition strategies and initiatives.
3. The standard CBA should be supplemented with particular analytical components like the unpredictability of climate scenarios, mitigation and adaption initiatives, and long-term adaptation interventions and securities in order to adequately reflect the impressions of climatic changes on agriculture sectors and associated hazards.

7.2 CBA of Climate Change Adaptation Options

In order to assess and prioritize adaptation strategies based on their societal benefits and costs, CBA is one of the methodologies that will be employed in the development of National Adaptation Plans (NAPs).

CBA is a method for evaluating all of a project's effects on all societal members economically. It's a technique for figuring out whether a project will be more advantageous than costly when assessed from the standpoint of society. To evaluate the benefits and drawbacks of a single entity, such as a company or organization, a financial analysis is employed. Contrarily, CBA's economic analysis aims to consider all benefits and drawbacks to the community as a whole, including social benefits and drawbacks to various recipients. As several studies have shown if benefits totally outweigh expenses and the initiative benefits society (Boardman et al. 2014). CBA's purpose is to ensure that society's resources are allocated efficiently by notifying legislators and public sector constituents about the economic productivity of different alternatives, interventions, and policy choices (Boardman et al. 2014). It can help the government decide whether or not to give financial resources to a specific project. The results of the CBA are used in the NAP process to appraise and assess diverse adaptation choices as part of the NAP execution. A wide range of screening criteria, including governmental, social, and other issues, can be used to integrate CBA data.

7.3 CBA of Agriculture Adaptation Options: The Basic Steps

CBA of agriculture-related adaptation programs may necessitate a large quantity of data, statistics, and skills from a heterogeneous team of professionals. Table 1 shows the basic CBA steps, which are outlined here.

Table 1 The major steps of CBA for agriculture adaptation projects

1	Define the parameters and scope of the adaption project's analysis
2	Give an explanation of the "with and without adaptation project" (WP and WOP) possibilities
3	Enumerate and monetize adaptation advantages and costs yearly over the course of project
4	Calculate the annual flow of net gains from agricultural adaptation initiatives
5	Quantify specific indicators for agriculture adaptation
6	Execute sensitivity analysis in relation to possible scenarios for climate change
7	Provide suggestions

(Boardman et al. 2014)

Step 1. The goal of this step is to define the scope and bounds of the analysis so that you may pick which benefits and costs to include. This will aid in laying out all of the accessible options, as well as determining which ones have genuine benefits and expenses. Project developers typically refer to the project's broad geographic scope (also known as the project area boundaries), and CBA compares the project's costs and benefits to the local people to what would have occurred if it had not been executed. CBA is used in both the analysis's "with project" (WP) and "without project" (WOP) contexts.

Step 2. Due to the possibility of instant variation occurring in a project region even if the project is not completed, the definition of the counterfactual scenario must be given special consideration (i.e., the WOP scenario is dynamic, assuming nothing will happen is an unrealistic baseline). When projects are unique, have extensive time horizons, or have complicated interactions among factors, making predictions is challenging. Climate modeling is used in climate change adaptation initiatives to describe climate situations as well as additional benefits or costs associated with adaption strategies. Benefits, for example, might be described as avoided climate change damage costs, whereas costs refer to the actual investments made in performing the adaptation activity.

Step 3. In both WP and WOP scenarios, it involves enumerating and make money all project profits and costs over the course of the project's life cycle. This necessitates:

- Determining the project's tangible inputs and outputs
- Within the scope of the analysis, identify project impacts using a cause-and-effect link
- Classify them as advantages or disadvantages

It comprises computing and monetizing all project advantages and costs over the course of the project's life cycle in both WP and WOP situations. This necessitates the following:

- Determining the tangible inputs and outputs of the endeavor
- Using a cause-and-effect connection, identify project impacts within the scope of the analysis
- Sort them into benefits and drawbacks

Give each benefit or expense an economic value. Practical inputs and outputs are appreciated at market charges to produce the fiscal statements with the underlying premise that prices reflect value). This financial study will assess how much the project will cost farmers, private and public companies, governmental organizations and other stakeholders. Giving each project's input, production, or influence, a monetary value is straightforward where markets are present and functioning well. Problems arise when market prices are no longer a reliable indicator of society costs and benefits, such as when markets for environmental goods are absent or inefficient, as they are in many developing countries. In these cases, specific techniques for determining "nonmarket" values or for altering the economic charges of actual goods to match economic values may be used. It was shown that new value assigned is the shadow price when the market price is transformed to more accurately reflect the opportunity cost to society. This section of CBA is also known as '"economic analysis," rather than "financial analysis." In addition to estimations of concrete cost-benefit factors and societal costs and benefits, intangible aspects such as environmental externalities should be considered in the CBA of adaptation options.

Step 4. Considers the fact that project consequences happen over time. Future expenses and benefits are reduced in relation to current costs and benefits to arrive at their present values (PV). Since values that occur at different periods cannot be compared. Discounting is the process of valuing future resources at a lower rate than equivalent present-day resources. This exemplifies the prospective cost of resources because alternative project expenditures could increase the amount of resources available into future. According to Boardman and associates (2014), there is a lot of discussion over what is the best public discount rate (Arrow and Kruz 2013; Gollier 2002; Weitzman 1998; Campos 2015).

Step 5. The evaluation of the project's total impact is a crucial step in determining the project's value to society. To do so, each option's net present value (NPV) must be calculated. The NPV is calculated as PV(B) – PV(C), where B is the PV of benefits and C is the PV of costs (C). The fundamental decision criteria for a single project are to proceed if the NPV exceeds the counterfactual. The standard is to select the project with the highest NPV when contrasting mutually exclusive alternatives. The Internal Rate of Return (IRR) for the suggested savings is also determined. The IRR represents the value of the discount rate when the NPV is zero. The IRR can be used to choose projects when there is just one choice to consider. The project should be pursued if its internal rate of return (IRR) exceeds the present discount rate (Boardman et al. 2014).

Step 6. Focuses on the significant uncertainty around both expected effects and the appropriate monetary value of each impact such as price volatility or fluctuations in crop and livestock productivity, due to the multiple changing factors that could ultimately alter the results of interventions. Although only the most significant expectations and parameters that are crucial to the analysis' outcome should be the focus of sensitivity analysis, every assumption in a CBA can still be changed. Performing CBA of adaptation alternative poses a significant difficulty since it requires processing various climate projections and taking into account uncertainty connected to climate change. Climate change and risk avert the use of expected values, demanding scenario-based analysis that considers risk evaluations and future climate forecasts. It is necessary to allocate probability while making long-term agricultural adaptation investments.

Distributions to numerous climate change situations to evaluate the sensitivity of the findings. In addition, it is challenging to predict the costs and benefits of slow-onset adaptation options that occur over longtime prospects (such as 25, 50, and 100 years), because the final NPV results are influenced by the discount rate used. As a result, it is important to consider the restrictions of ex ante CBA in light of the unpredictability of the weather. Additionally, the computed costs and benefits must be roughly estimated.

Step 7. It's value emphasizing that CBA is a rigorous analytical process that gives objective data and results to the decision-maker. Assumptions made during the study should be substantiated by factual data, checked with important specialists, and documented in a transparent manner.

8 Conclusion

CBA is a decision-making tool that evaluates how capitals should be distributed between various alternatives in order to achieve monetary competence. CBA is chosen as a key input to the planning process as a primary methodology in the production of the NAP. The NPVs of adaption alternatives can be calculated using CBA under various climatic scenarios. Climate change uncertainties, as established by Hallegatte (2009), present new challenges for decision-makers and, as demonstrated by Pindyck (2007), significantly complicate CBA, which must depend on climate change-related models and data.

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Climate Change and Social Concerns

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Abstract The climate is changing constantly, and this change is affecting millions of people to encounter extreme challenges to *health, migration, water security, livelihood security, cultural identity, food security*, and many other related risks. Climate change is deeply entangled with global patterns of *inequality* affecting beyond *375 million* people every year with an escalation of 50% as compared to the previous decade. This increase is giving rise to social issues such as poverty, unemployment, unequal opportunities, racism, and malnutrition, which are affecting many people. The investigation and analysis of social issues is an important research theme as it is significant to make people think of ways and approaches for problem solving through critical thinking and *mitigation approaches*. One of the major effects of climate change is that our social *harmony* is disturbed, and it is giving space to hostility and suspicion. It has caused large-scale social dissatisfaction and created suffering and misery. In this chapter, we summarized the trepidations of climate change and social concerns that are penetrating in developing countries. The study calls attention

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_3

to the inevitability to develop and spread evidence-based interventions to combat the risk in the wake of climate change. There is a dire need to promote social cohesion and community resilience to mitigate the possibility of social conflict in changing climate.

Keywords Climate change · Social impact · Social indicators · Food security · Livelihood security · Mitigation · Sustainability

1 Introduction

1.1 Climate Change

Humanity's greatest environmental hazard is climate change. Climate change and global inequality are intricately connected. Climate change affects the most vulnerable individuals, yet they contribute the least to the problem. Life-threatening occasions, healthiness implications, food preservations, living safety, and water security are all becoming more difficult for millions of people because of climatic variations (Cohen 2021). The amount of heat-trapping gases in the earth's atmosphere has a significant impact on the planet's climate (NCA 2019). According to the Intergovernmental Panel on Climate Change (IPCC) "Climate Change" refers to a long-term shift or change in the climate characterized by changes in the mean or variability of its features (IPCC 2019). The temperature of the Earth's surface has increased by approximately 1.40 °F (0.80 °C) over the past century, with 1.0 °F (0.60 °C) of this increase occurring in the last 30 years (ACC 2011).

Additionally, the IPCC claimed that natural internal processes referred to as external forcing, as well as persistent human modifications of the atmospheric or terrestrial use, might contribute to climate crisis (IPCC 2011; Rehman et al., 2021; Rasool et al. 2020a, b, 2021; Mehmood et al. 2021; Hussain et al. 2020a, b). To put it another way, climate change is a word that refers to long-term, major shifts in the atmosphere. Forces that may affect the ionosphere, solar radiation, mountainous formation, ocean circulation, and variations in warming effects are all instances of such factors (NASA 2016; Ali et al. 2019; Qasim et al. 2020; Mubeen et al. 2020). Changes in the sea's mobility over brief periods, like a consequence of climate change, oceanic fluctuation, and motion, such as the El Nino Southern Oscillation (ENSO), which affects the Caribbean, are frequently to blame (MPIBGC/PH 2013). International leaders agree that climate change will be one of the greatest threats to human well-being in this millennium. Issues to current knowledge of suitable objectives for policy reforms, such as the link between progress and opulence and equality and sustainable growth are raised. As a result of human-caused environmental issues, civilizations and cultures around the globe are increasingly concerned about their protracted viability. Global governance institutions are likewise facing unprecedented hurdles in dealing with the phenomenon's scope and influence. Based on an improved knowledge of the links among changing climate, susceptibility, social justice, and equality, this chapter aims to provide an agenda for future study and activism (Sahney et al. 2010b; Zainab et al. 2020; Hammad et al. 2020; Hashmi et al. 2020).

A social development perspective on climate change means that we begin by framing the issue in order to achieve equality across various layers of society, especially worldwide to regional to domestic. There is a strong link between changing climate as well as the worldwide distribution of wealth. It tries to reverse the progress made in reducing poverty and ensuring that the Millennium Development Goals are met (UNDP 2007). Due to lack of resources and inequity, people's susceptibility is inversely proportionate to their share of responsibilities, and the need of action emphasizes to social justice and mitigation process (McMichael et al. 2003).

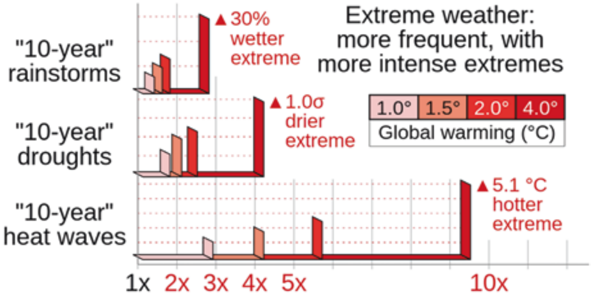
1.2 Climate Change Impact on Humans

People's well-being is directly impacted by everything: from catastrophic event to the demolition of their own houses to mass migrations to conflicts over water and food. The impacts are often much in developing countries, that is, Bangladesh, Cambodia, the Philippines, Maldives, Bhutan, Thailand, Sri Lanka, Pakistan, India, East Timor, Guyana, South Sudan, Central African Republic, and Ethiopia. Geomorphological, biochemical, and environmental institutions may have been permanently altered because of climatic modification (ACC 2011; Shahid et al. 2020; Zamin et al. 2020; Hussain et al. 2020a, b; Ali et al. 2019). Extreme weather (MPIBGC/PH 2013), increased risk of wildfires (Tang et al. 2015), loss of biodiversity (Sahney et al. 2010a, b), strain on food-producing systems, and the worldwide spread of infectious diseases have all emerged as a result of these changes in the climate (McMichael et al. 2003; Wang et al. 2019; Fahad et al. 2019). In addition, the World Health Organization predicts that between 2030 and 2050, the yearly death toll from climate change would rise to 250,000. In 2002, this death toll was estimated at around 150,000 (WHO 2019) (Climate change and health, 2020). People's health, access to food, job creation, relocation, protection, and social transformation are just some of the ways climate change is affecting people's lives. The long-term impact of these alterations is expected to be negative. As an example, climate-sensitive illnesses like dengue, communicable diseases, gastroenteritis in children, and pneumonia have increased among Bangladesh's vulnerable populations (Kabir et al. 2016). Climate change's present and future effects on human civilization are expected to continue to be predominantly negative, according to several research (Ghfgeneva.org 2011; Oxfam 2012).

Globally, impoverished and minimal groups are more vulnerable to natural health outcomes and wealth than their wealthier counterparts because of climate change. They both have a far lesser potential for adapting to ecological concern than other species. An estimated of $125 billion was spent on improving social indicators in developing countries due to severe droughts and flooding (Climate Change 2021).

1.3 Key Vulnerabilities

Vulnerabilities include severe meteorological occurrences, sudden rising sea levels, and restricted availability of capabilities (monetary, technological, and personal) to respond. The IPCC released a study in 2007 identifying the most critical climate change vulnerabilities for business, communities, and civilization (Wilbanks 2007; Shah et al. 2019; Shahzad et al. 2018).



Source: IPCC 6th Assessment Report (2021) horizontal & vertical bars showing large scale increases with extreme weather conditions, for increasing of global warming. (Climate Change 2021)

1.3.1 Very High Confidence

- This is especially true in poor nations, where urbanization tends to be concentrated in coastal towns that are highly vulnerable to climatic disruption.

1.3.2 High Confidence

- Stresses resulting from climate change are connected to both the effects of climate change and even the effects of climate change policy.
- Connections among environmental threats and productivity expansion should alter by mandating increased energy options.
- There are a number of infrastructural facilities that are critical to satisfying human requirements, including those that are vulnerable to severe tropical storms or coastal flooding, and those that are already near to becoming insufficient.

1.3.3 Medium Confidence

Involvement in legislative, societal, and customary conditions that are already subject to additional demands, such as controlled productive materials, is crucial. According to a study by Xu et al. (2020), it is projected that by 2020, one billion people will be residing in areas where the heat is considered too severe for basic subsistence.

This scenario, according to the study's supplemental materials, predicts that global mean temperature would be 3.2 points warmer in 2070 than it was before industrialization (*Supplementary Materials*, *Future of the human climate niche*, 2020).

1.4 Health

People's well-being is threatened by a broad variety of climatic condition-driven issues. If climate temperatures boost along with current given pace, these hazards might rise to dangerous proportions in the subsequent century (McMichael et al. 2006). Extreme heat, increased air smog, and environmental catastrophes are just a few examples of the damaging consequences of human activity on the environment. Other examples encompass variations in plant returns, the ecosystems of mosquitoes, and the efficiency of either the sea or oceans. In addition, there are indirect effects such as dislocation and dispute accented with scarce resources, such as rain, and long-term effects on health after a tragedy.

Climate change poses a challenge to worldwide efforts taken to reduce infant undernutrition, waterborne disorder fatalities, and even the development of some of the other viral diseases. Global warming exacerbates current medical concerns, primarily in the poorest areas worldwide, especially in developing nations. People in underdeveloped countries are already suffering from various negative health effects due to current weather variations (Bulletin, 2019), and these are only going to become worse because of the additional strains brought on by climate change.

In order to maintain a healthy society, safe drinking water, enough nourishment, biological limits on communicable diseases carriers, and a safe and secure home are all essential. There is a correlation between a hotter and much more erratic atmosphere and even an increase in certain air pollutants. Modifying vector organisms (such as mosquitoes) and the distribution of intermediate host species that harbor the weakened virus can increase the transmission rates and geographical ranges of infectious diseases (such as those carried by cattle, bats, and rodents) (Lunde and Lindtjørn 2013). Agricultural productivity in many places, along with some of the least developed nations, is negatively impacted by changes in temperature, rainfall, and seasonality, jeopardizing the health and development of children and the general health and functional ability of adults. A number of locations throughout the globe have seen an increase in the intensity (and may be frequency) of weather-related catastrophes in recent decades as a result of global warming (Munich Climate-Insurance Initiative 2013).

There is a strong connection between medical disparity and climate science, which has a profound effect on human mental well-being. Lower-income families will bear a greater part of the cost leading to increased exposures and sensitivity to health hazards, according to the World Health Organization's Commission on Social Determinants of Health. Malaria and diarrhea kill more than 90% of children under the age of 5, mostly in underdeveloped nations (WHO 2009). Workers in tiny island emerging terrain as well as massive super and steep aspects are among the other populations who have been particularly hard hit by climate change (Human Development Reports 2011).

1.5 Environment

Anthropogenic global warming may have a significant influence on biodiversity degradation, such as the destruction of woodlands, as seems to be the case in the past, due to drier circumstances (Sahney et al, 2010a, b).

1.5.1 Temperature Variations

At a persistent moisture heat of 35 °C, physiological organs are never more capable enough appropriately to cool the skin. NOAA in a 2013 research indicated that overheating would have a significant impact on labor productivity given different pollution projections (John et al. 2013). Extreme temperature readings have been shown to influence the fatalities of fetuses and infants (Currie and Deschênes 2016). Thermal stresses are generally discussed in terms of their effect on wellness, but they could also affect achievement of the students and production, which can have negative consequences for the prosperity and growth of a nation.

1.5.2 Low Temperature

Disruption of the weather pattern owing to a decrease in Antarctica is a serious environmental problem. Temperatures in certain regions of the northern hemisphere, such as southern states of North America, the Midwestern, and areas of Europe, are now experiencing bitter, cold air spilling outside the Artic (Polar Vortex, 2018). This is a wintertime result of global warming that is expected in the near future. Human existence is severely disrupted as a consequence of the sudden drop in temperature. More than $263 million overall devastation, 32 deaths, and numerous injuries were inflicted by the most significant winter storms of the 2013–2014 season, according to statistics from the winter season (Ryan 2014). In addition, the Northeast and other portions of the Midwest and Southern Americas were affected by widespread destruction in the guise of shuttered highways, colleges, ports, and other public operations with cost of $ 4 Million.

1.6 Water

The aquatic supplies that people depend upon are also very vulnerable by climatology changes. (Heidari et al. 2020). As a result of long-term climatic changes, people's interactions with freshwater throughout the world have been fundamentally altered. All parts of the world have a net negative effect from climate change on water supplies and freshwater communities, stated by IPCC during 2007 (Kundzewicz 2007). Arid and semiarid regions are especially vulnerable to hydrological effects, according to the IPCC (Glossary, 2021). From 2000 to 2100, the IPCC predicts that there will be more variability inside the quantity and frequency of rainfall (Glossary, 2021). Freshwater availability and quality are affected by climatic variation because of fluctuations in worldwide precipitation, drainage, snowfall, interflow, and certain other variables. These are only a few examples:

- Hot water has a negative effect on the ecosystem and has the potential to speed up contamination in bodies of water.
- Saltwater intrusion into groundwater is expected to grow as sea levels rise. Freshwater supplies are reduced as a result of this practice (EPA 2009).
- In certain regions, the water supply is threatened by the diminishing glaciers and snow deposits.
- Late summer and early spring peak flows will likely be reduced, with less water throughout the midsummer and earlier spring peaks happening.
- Crop irrigation may be affected. South American irrigation, Central Asian irrigation and drinking supplies, hydropower in Norwegian, the Mountains, and the Pacific Coast of North America are especially vulnerable to water shortages (News, BBC, 2003).
- When more water falls on hardened land that can't soak it up, flash floods result instead of replenishing soils or groundwater levels (Climate Change and Mental Health, 2018).

1.7 Agriculture

In both agriculture and climate warming, the unfavorable impact of global warming is felt both internally and externally through agriculture, and both processes are global in scope. There are a number of ways in which this might occur, including variations in median degrees, precipitation, climatic extremes (e.g., heat waves), pests, and illnesses; variations in greenhouse gases in the atmosphere and subsurface ozone quantities; and changes in sea level (Climate change, 2021).

Agriculture is already being affected by climate change, but the consequences are not fairly spread. Crop output in low-latitude nations will almost certainly be severely affected by future climate change, although impacts in northern latitudes might be beneficial or negative. Climate change is further exacerbated by greenhouse gas emissions from animal agriculture.

1.8 Oxygen Deficiency

Climate change was already linked to an extinction event of people if the planet warms six Celsius beyond pre-industrial values. As a result, phytoplankton, which provides a major portion of the Earth's land surface, might be harmed by these circumstances (Sekerci and Petrovskii 2018), (Failing phytoplankton, 2021).

1.9 Dislocation and Migration

One of the most prominent ways that climate change causes people to be displaced is by increasing the incidence rate of rain and wind catastrophes, which lead people to relocate and hide away somewhere. Deforestation and increasing ocean temperatures are eroding people's livelihoods and forcing them to relocate to more hospitable locations. Areas in Africa's Sahel, the moderately agricultural zone that runs from north to the south, are now experiencing drought. The escalation in conflict for resources as a result of climate change might result in the displacement of people (Environment a Growing Driver in Displacement of People, 2009).

Catastrophes in the Asia-Pacific region are more common than in any other location on Earth, with more disasters occurring and affecting more people. There are many vulnerable populations in the area, many of whom are impoverished and disadvantaged, and the area is particularly sensitive to climate change consequences. "Environmental hot areas" have been identified by the Asian Development Bank in a recent research as places where floods, storms, strong winds, and waterlogging are most likely (First wave, 2013).

At-risk areas' environmental circumstances have pushed many governments to pursue a variety of strategies, including social protection programs and fundamental urban infrastructure improvements. Migration may be reasonably sensitive to external disturbances, according to certain researchers. Immigrants, especially cheap workers, have been among the greatest disadvantaged persons in civilization, and most have refused fundamental rights and accessibility.

1.10 The Way Forward: Integrated Climate Change Policy Responses and Mitigations

People's vulnerability to environmental threats may be assessed by looking at how climate change impacts their daily lives and the social factors that make them susceptible. As a result, climatic warming offers a significant threat to conventional regulations since it spans a wide range of industries and challenges. Climate change policy solutions should not be segmented into a variety of industry objectives, including electricity, transportation, agriculture, and so on. A fragmented response to climate change does not appropriately react to it. It is still common practice to use a sectoral approach to address climate change, predominantly regarding the prominence on "end-of-pipe" approaches of vindication of the gas emission as greenhouse effect, such as revenue system, vocation strategies, and digital reaches, which do not sufficiently involve social architecture or repercussions of these methodologies. According to past research, such strategies have not been effective, and a wider approach is urgently required. If climate policy embraces the social elements of climatic changes and a solid social column arises to support the conventional scientific and ecological aspects, significant societal and financial possibilities may be taken.

1.10.1 Seizing Opportunities

Climatic disruption presents an innovative modification to world leadership, necessitating countries to handle historically separate challenges in an interconnected fashion and rethinking their macroeconomic policies in light of this new reality. In addition, initiatives that include communal discussions right the start may contribute to people discovering and uniting behind other connected development challenges, for instance, monetary improvement in addition to occupation prospects and admittance to decent aquatic reserves, hygiene, and well-being maintenance. To be sure, global climate activism and collaboration is essential to the development of comprehensive and transformational welfare movements and sound government.

1.10.2 Responding to Knowledge Gaps

Recognized societal and hominoid disciplines, as well as home-grown and unceremonious awareness, are primarily responsible for the lack of information on the social aspects of climate change. Some examples of the kinds of information that are needed are statistics on catastrophe impacts that are split down by gender and age, information on climate-sensitive illnesses, and forecasts of how climate change will affect migration. The following methods are advised in response to these gaps:

1. In addition to scientific knowledge systems, it is important to value informal/local/traditional knowledge.
2. Collaborative research on climate-related challenges should be supported through national and international collaboration.
3. As part of the WMO-led Global Framework for Climate Service, support initiatives to promote microclimate discipline rationalizing in key subdivisions, for instance, well-being, catastrophe menace decline, nourishment, and H_2O sanctuary.
4. The UNFCCC's National Adaptation Programs of Action and National Communications should be strengthened to include social elements.

1.10.3 Refining Climate Policy Processes

Regulations must be established and implemented consistently keeping the underlying process concepts in mind. Societal policymakers has to be "extensive, reactive, and responsible" in order to successfully enable men to act as actors inside the combating climatic alterations and to facilitate their transformation "commencing themes and recipients to inhabitants through privileges and obligations." Additionally, it is critical to include good governance, and these values into the design of climate policies in order to retain public faith in government expenditure and investment. Transparency International's Global Corruption Report: Climate Change reaffirms the need of strong global governance for implementing successful climate measures. According to the survey, nations that are most susceptible to climate change are frequently ones having the worst worldwide bribery scores. Corruption and poor governance, like other development concerns, may jeopardize attempts to mitigate climatic catastrophe. Additionally, significant infrastructure expenditures or economic movements that are susceptible to sleaze are required to attain worldwide less in carbon cost-effective expansion; it is critical that controls and institutionalization be in place to avoid mismanagement. A significant improvement of political structures based on known concepts may increase the likelihood of global warming initiatives succeeding.

- *Contribution*: Active engagement gives everyone a real chance to affect or improve policymaking, execution, and administration. At all levels, from national policy to local choices on transit, property utilization, accommodation, and other issues, different participatory methodology would be required. In all circumstances, human rights activists and localities, particularly labor unions and employers' associations, must be included in the early stages of decision-making. There is a greater danger of services that do not meet people's needs or objectives, being unsuitable in terms of price, and are unrealistic in terms of payment alternatives if impacted organizations are not included in the development and choice process.
- *Responsibility*: International humanitarian accords, employee rights, and national constitutions and laws all require states to uphold their promises. There are three ways to understand the human rights concept of responsibility in climate change: The identification of content providers (with respective claims) including matching duty holders (and their respective responsibilities) defines basic areas of accountability (whom performs when and what along with responsibilities). As a result, it examines that both responsibility bearers' desirable and undesirable responsibilities (to preserve, develop, and execute). Within framework of interference projects, it stresses the "greater accountability" of obligation toward the constitutional protections it strives to uncover domestic policies for corrective action. Performance monitoring mechanisms must be implemented through converting quality requirements to regionally established goals and targets for assessing success in this process as well. Whenever laws are broken, a "cure" is required, and this necessitates the establishment of methods and processes for

filing complaints that are both easily functional. Regulatory boards and courts; investigative committees; specialized offices; some will all be included in this category of entities.

- *Nondiscrimination and Equity*: Global warming disaster risk reduction strategy must pay significant attention to the position of disadvantaged, prejudiced, and marginalized people. There must be a deliberate process to understand the disadvantaged and underprivileged people or organizations who will be particularly affected by climatic disruption and/or climate change legislation. Equitability in potential as well as procedure, along with egalitarian results, must be ensured by taking aggressive efforts to guarantee all regulation include such communities into the judgement methodology. There are many other groups that are at risk of HIV infection, including women and children who live in rural and devastated by the loss city centers, as well as people who have been forced to flee their homes due to war or natural disaster, as well as those who have been displaced from their homes due to migration or internal displacement.
- *Empowerment*: It is imperative that any and all climate change-related choices, policies, and activities empower local stakeholders while avoiding reinforcing any existing power disparities. As a result, solutions must help right-holders acquire or use the entitlements more effectively. Services that help individuals suffering from hardship engage at all stages of the policymaking system, audit public spending using affordable and widely usable societal transparency or auditing techniques, and continue to fight for rights are all examples of what is necessary. In this way, empowerment is a prelude to effective climate change measures and a social good in and of itself.
- *Transparency*: There should be complete transparency in the preparation of climate change mitigation and adaptation policies and actions. A policy of openness and transparency is needed to ensure that all stakeholders are aware of the plan's approach, goals, and guidelines; that climate change-related documentation is accessible online; and that press releases are issued to publicize the planning process and to make records of meetings available.
- *On the basis of the above, the following policy recommendations can be made*:

    1. In order to accurately detect macroeconomic weather variation "hotspots," it is necessary to combine earth's weather studies alongside social benefit evaluations. Threats pertaining to a particular community may be inadequately or overemphasized by climatological study, which is not tailored to that city and its residents. It is important to incorporate and combine the results of downscaling with complementary mappings such as social impact assessments and vulnerability maps in order to identify social climate-inflicted spots (locations in which extremely devastating troubles will have to be resolved) as well as their interconnection to both these sorts of security flaws like a deficiency in connectivity to preventative and remedial care facilities that could still reduce damage disaster risk. Evaluating implications on unemployment, nutrition security, gender, youths, and small-scale farmers should be included in a comprehensive impact assessment.

2. Increase the frequency of community development evaluations and improve the quality of the data. Due to the fact that social impact evaluations are seldom carried out concurrently alongside the formulation and construction of environmental legislation, the initiatives usually fail to include critical user feedback regarding possible restrictions or possibilities. Insist on the performance of social impact evaluations at every level of research and program creation, from conception to implementation.
3. Encourage intergovernmental cooperation and integration as well as conversation to be more effective. At the moment, ministries, international organization, and government agencies often function in silos, failing to address the intricacies of climate change effects and founder uses to the fullest extent possible. At both the international and national level, for nation ministries to engage in discourse about climate policy must be made accessible, and their knowledge will be included within regional and domestic policy initiatives. To ensure that educated and community-led choices are integrated into these fora, liberal democracy must be represented at such meetings. To ensure the climatic measures are conceived and executed across global priorities in social, economic, and environmental development, these fora should be enabled to ensure coordination and alignment with national development plans.
4. While developing and implementing climate solutions, be certain that safeguards are in place to protect the interests of the most vulnerable people. With the findings of assessment methods and causation studies, it is important to include the particular socioeconomic factors of global warming sensitivity when determining the real issues of susceptibility and adaptive capacity for climate change. In ensuring that regulations are sufficiently mutually supportive and will not have a negative effect on the most disadvantaged, they must be reviewed often.
5. Make an intellectual resource development. Environmental programs and legislation now have ability to facilitate individuals to act as implementers and pioneers in their own communities. The advancement of education and skill-building possibilities must occur all thru the execution of policy measures, guaranteeing that individuals have been prepared for the future to devise with their roots solutions, even though the greatest disabled groups are enabled to reduce their hazards.
6. Make certain of the massive structural improvements required for reduced development need not worsen existing inequalities in society. Lawmakers must ensure that communities where renewable energy investments, sea walls, and large-scale irrigation systems are being constructed have the necessary skills to adapt to these changes. This will ensure that (i) such investments contribute to livelihood opportunities, and (ii) social unrest and inequity do not result from these major transitions.
7. Incorporate climatic financing on a global and regional scale with social components, such as budgeting that is sensitive to societal needs. In order to construct a social aspects budgeting tool, use current budgeting criteria like

childcare, well-being, and female planning. The program will analyze whether worldwide funds now given in financing equally help social context, allowing politicians to distribute fairly again for different aspects of changing climate.

8. Ensure that environmental financing is in supplementary to the statutory infrastructure support already in place. Taking money away from the development of a project might have serious effects. The global community on environmental issues must be guided by the premise of delivering innovative or extra support to enhance baller, reduced, and climate-resistant growth. There should be an emphasis on reducing poverty and addressing climate change, which will eventually contribute to the development agenda MDGs.
9. Review various shortages and recommend topics for further study. Knowledge gaps often develop while creating climate policy, in addition to the rigorous scientific gaps relating to the social elements of environmental issues. Studies should be grounded in native culture as well as answered by drawing on the experience of public organizations, such as those dealing in meteorology as weather, as well as experts from other fields of study. As with causality analyses, social effect assessments assist identify research gaps. An important resource for policymakers is the International Human Dimensions Program on Global Environmental Change.
10. Low-carbon growth policies that promote health co-benefits while also including education and livelihood skills building and climate policies that are gender-sensitive are all recommended.
    - Development and infrastructure investments will benefit from improved governance and transparency.
    - Climate policy that is sensitive to the needs of women.
    - Communities that are cohesive in their implementation of climate policy.
    - Specific climate money that does not replace ordinary monetary support is being sought.

1.11 Conjunction of Agendas into Benefits with Crosscutting Inferences

1.11.1 Urban Development

Industrial and population development is localized mostly in metropolitan regions. Over about 50% of the globe's inhabitant's lives in metropolitan centers, which are anticipated to grow beyond their existing 3.4 billion toward 6.4 billion through 2050. Despite the fact that metropolitan areas are the major source of environmental energy pollutants and consumerism, cities often provide superior opportunities for lengthy ecological but also socioeconomic progress. Condensing populations and using efficiencies of magnitude in urban planning may lower with per expenses and power consumption while also increasing population stability and reducing stress on natural resources in the surrounding area. Additionally, urbanization has a crucial role in childbearing drop, as well as in the independence of females. Think of an investment for urban expansion, especially via the provision of land and houses for the urban poor, increases people's ability to adapt. It has the potential to improve efficiency and accessibility for everyone but especially for the poor and those most at risk from the effects of climate transformation. An approach to urbanization and poverty alleviation that is well thought out and implemented is a winning strategy.

1.11.2 Health and Nutrition

Noise pollution mitigation and adaption techniques have a wide range of positive effects on human well-being. Pulmonary and bronchial disorders, freshwater and raster infections, and starvation caused by agricultural scarcity may be reduced by reducing pollutants or delaying environmental degradation. Biofuels are being used by 2.4 billion individuals to prepare and energize their homes, putting their safety at risk while also accelerating climate change. Reducing indoor air pollution by replacing cook stoves with low-emission alternatives will save an estimated 2 million lives a year, especially for ladies and kids. Environmental warming adaptation measures need enhanced health infrastructure and services. These healthcare initiatives help to grow human assets and decrease impoverishment and thereby strengthen the resistance of entire homes and localities to the effects of climatic disruption. Decreased toxins and a decrease in obesity prevalence are two additional benefits of encouraging people to use social transportation (particularly strolling and bicycling).

1.11.3 Sustainable Livelihoods and Employment

Although some people are concerned about the negative employment implications of climate change, efforts to combat it will result in the development of new "green jobs" as in future generations, defying popular belief to the opposite. The provision of sustainable energy at countryside community in distinctive has the supplemental cross of propping up its self-sustaining development of tiny cities, empowering the creation "eco-friendly" corporate organizations, diversifying income sources in areas where agricultural decline is expected as a result of climate change, and increasing the likelihood that the poor, particularly women, can participate in these enterprises if they are relieved of the time-consuming task of getting funds. There might certainly exist possibilities for "eco-friendly" occupations that were traditionally assumed "unclean," which may be beneficial to both the health of people and the environment. A just transformation of the manpower, particularly in sectors that are strongly reliant on cretaceous energy harvesting including using [like the petroleum as well as lignite industry fields and some energy-intensive industries that are unable to easily transition to renewable energy] will necessitate the implementation of additional social protection measures and training, which can open up fresh possibilities for national economy.

1.11.4 Disaster Risk Management (DRM)

One crucial component of combining sustainability adaption to climate severe occurrences would include the creation of holistic hazard along with vulnerability abatement approaches, since doing so would serve all objectives. Severe climate occurrences, such as a greater incidence and scale of environmental catastrophic occurrences, would quite probably become increasingly regular as a consequence of climatic variations, which may response in increasingly severe climatic trends. Weather and climatic pressures in the territory have been changing, and societal changes are occurring continuously, such as demographic shifts and the global expansion of urban settlements in coastal areas. As a result, it is likely that people will become more exposed to and vulnerable to extreme events in the future. Therefore, methodologies that assist to connect the competence in numerous societies, such as adaptive capacity and mitigation, acclimation, financial services, and also infrastructure intending, could indeed serve to enhance adaptability as well as lower the threat, which exists, or lifestyles will be ended up losing or hurt as a result of climatological anthropogenic negative impacts.

2 Conclusion

Viewing climatic sensitivity via a socioeconomic timeline's perspective provides a more complete picture of the sociodemographic variables that render individuals susceptible in initial instance in personal and organizational assets, institutional regulations with control imbalances. It is essential that adaptation plans target societal causes of fragility throughout terms of improving the resilience of the most susceptible individuals and populations. Societal structures such as medical facilities and entitlement programs, along with individual variables, which play a vital role in public's ability to adapt to climatological disruption, would always been considered via the prism of the cultural aspects. More than a dozen international organizations evaluated the causes of climatological alterations in nationwide, continually embedding socioeconomic evaluations in handling a beneficial and adverse repercussions of climatic transformation, as well as transmittance or rather collaborative judgement mechanisms. This means that climate change strategies that include social aspects are not only correct in theory but also correct in reality.

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Unpredictable Weather and Agriculture-Based Economy of Developing Countries

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Abstract Climate change is now seen as an established challenge, and its consequences are being felt across the world. Principally, it affects the people and food chain systems, but its influence would also affect every aspect of the economy. Agriculture is important for food security as a source for food and, more importantly, the primary source of livelihood incorporating about 40% of the world's total workforce. Overpopulation, especially in developing countries, amplifies the demand for agricultural products. The weather in different parts of the world is becoming increasingly divergent from the norms of the local climate. The temperatures are increasing on a regular basis, and precipitation is becoming more unpredictable. The weather-based extremes, including heavy downpours, flooding, extremes of both heat and cold, storms, and a prolonging of drought are occurring more frequently. In the climate change context, the agricultural sector has been the most badly affected. Climate change effects have been reduced through the application of state-of-the-art forecasting systems and modernized farming technologies. However, those are inaccessible to the underdeveloped or poor states of developed countries. These states have agrarian-based fragile economies and are incapable of bearing any loss due to climatic extremes. In addition, the continuous availability of water throughout a cropping season became a substantial challenge which has enhanced the application of dryland farming on a wider scale. In this scenario, the responsibilities of the stakeholders, from planners and breeders up to the growers,

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_4

are more pronounced. International partners, such as the Food and Agriculture Organization(FAO) are working on various schemes to cope with these issues.

Keywords Seasonal rainfall · Agriculture · Temperatures · Food security · Seasonal rainfall

1 Introduction

Uncertainty and severity of global weather systems have posed substantial potential threats to agricultural production. Climate extremes are happening more frequently, making the food security issue an increasing challenge. In particular, the uneven and erratic patterns of rainfall over most parts of the world have made crop water management more difficult to handle. Accordingly, it has been forecast that it would become much harder to cope with issues of food security by 2050 (Ali et al. 2017). Climate change has been posing negative impacts on the efficiency of natural resources, principally including soil and water. It is becoming difficult to feed the increasing global population in the present state of climate change. The arising challenge of food security emphasizes the need for collective efforts on the part of all stakeholders to improve agricultural production (FAO 2019). Furthermore, the impacts of climate change are being felt across the world, and the people started considering the problem. However, developing countries are more vulnerable, with rudimentary infrastructure and a limited capacity to modernize their agricultural practices.

The consequences of climate change are more pronounced in those regions with lesser income and inadequate resources to adopt modern effective technologies. These include the arid to subhumid countries of South Asia and Africa. The farming sector in these regions does not have the financial or the technical potential to cope with the emerging challenges of climate constraints (Kurukulasuriya et al. 2006). In South Asia, around 18% of GDP is generated through the agricultural sector, and over 50% of the local population is dependent on farming-related industries (WB 2012). Agriculture is the major livelihood, with around 70% of the population engaged in the sector. In addition, about 75% of the people are poor and cannot afford to apply modern techniques or tools of cultivation to improve their production (WB 2012; Vermeulen et al. 2012).

Northern parts of South Asia, Himalaya, Karakoram, and Hindukush host the world's third largest snow/ice reserves. These mountains are the water tanks over the roof, providing water to the reservoirs in the downstream. The environment has been controlling this tank in terms of temperature following the strong buildup of greenhouse gases (Chaudhry and Rasul 2007; Akram et al. 2019; Ahmad et al. 2019; Sabagh et al. 2019; Danish et al. 2019). The glaciers over the Himalayas are melting rapidly and may disappear by 2035. As a result, the areas in the downstream regions may be increasingly prone to floods and droughts (Misra 2014). Agriculture, in terms of climate, is dependent not only on rainfall but also on irrigation water, which comes from seasonal rainfall as well as the melting of snow and ice. South Asian countries such as Pakistan have developed the world's largest contiguous canal irrigation systems.

In this study, to represent South Asian region as well as the developing countries in the climate change context, the researchers have drawn on the Met/Agrometeorological data of Pakistan. Further, to analyze the related impacts on the agricultural production, the wheat crop, as a major component of food security, has been discussed.

The major agriculture plains of Pakistan are irrigated through the Indus River and its tributaries. These rivers are mainly dependent on the seasonal rainfalls over the Indus basin as well as the melting of snow and ice in the Himalayan region, which is located in the north (Chaudhry and Rasul 2007; Iqbal et al. 2019; Khan et al. 2019; Amin et al. 2018a, b). Rainfalls in the Monsoon season occur during the summer period, from July to September. This season is considered the backbone for the country's agriculture because, in addition to meeting the peak demands for Kharif crops during the summer, it helps hoarding the soil moisture for the upcoming Rabi season in winters (Ghazala and Rasul 2011). The summer monsoon is the major rainfall season in the country; between July and September about 60% of the annual total rainfall occurs (Rasul et al. 2004; Rahman et al. 2018; Nasim et al. 2018a; Hammad et al. 2018a, b). However, it is mainly concentrated during the months of July and August (Ding and Ke 2013; Ali et al. 2018; Tariq et al. 2018; Awais et al. 2018; Rasool et al. 2018; Fahad et al. 2018; Afzal et al. 2018; Amin et al. 2018c; Khan et al. 2018). In addition, the pre-monsoon months, that is, May to June, have generally been very hot and dry due to occasional rains through convective localized systems (Rasul et al. 2004; Nasim et al. 2018b). On the other hand, the summer monsoon remained particularly unreliable because of its inconsistent nature. Its fluctuations have resulted in disastrous situations in terms of flooding or drought in the downstream areas. In particular, the drought-prone southern parts of the country, including Sindh and Baluchistan provinces, were particularly badly affected (Rasul and Kazmi 2013). The agriculture sector has been significantly affected by climate change. The availability of water throughout the cropping season plays a key role, but it's likely to be disrupted in future by increasing temperatures (ECP 2019). The historical data record of rainfall and air temperature highlights the complexity of climate conditions over Pakistan region (Fig. 1).

One of the principal natural resources that Pakistan is endowed with is "arable land." About 28% of Pakistan's total land area is under cultivation and it is watered by one of the world's largest irrigation systems. In addition, of a total land area of 79.6 million hectares, only 16 million hectares are suitable for irrigated farming in Pakistan (Rasul and Kazmi 2011; Awais et al. 2017; Hashmi et al. 2018; Adnan et al. 2018). Pakistan, like most of the developing world, is faced with the challenges of being affected by land degradation and desertification, which are causing environmental problems, including soil erosion, the loss of soil fertility, flash floods, salinity, deforestation, and an associated loss of biodiversity and carbon sequestration. Aslam et al. (2008) stated that waterlogging is another threat, since it causes severe damage to the production of major crops, including wheat, cotton, and sugarcane.

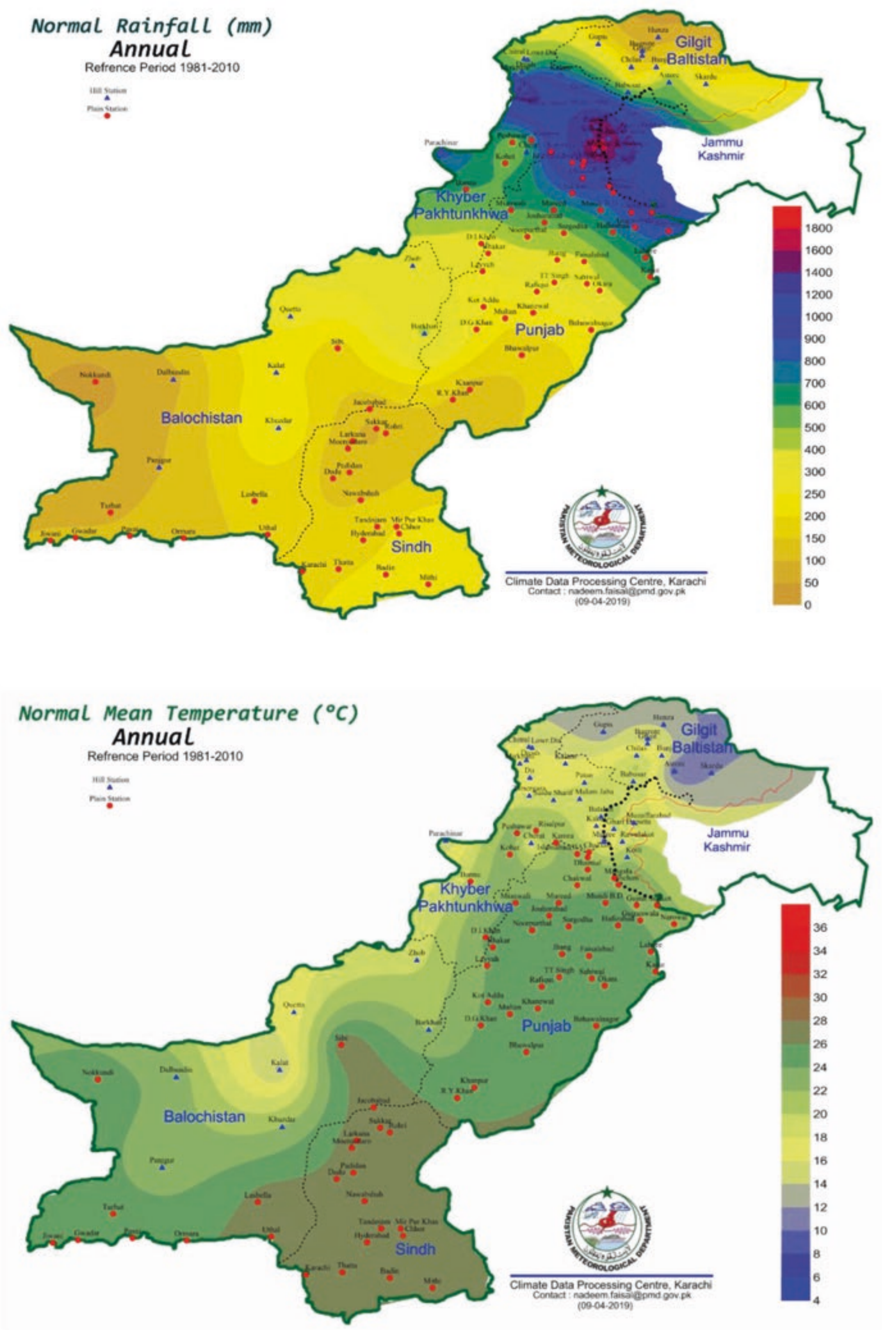

Fig. 1 Annual rainfall (left) and mean temperature of Pakistan. (Based on Climatic Normals for 1981–2010. Courtesy: Computerized Data Processing Centre of Pakistan Meteorological Department, available at http://www.pmd.gov.pk/cdpc/home.htm)

2 Data and Methods

Monthly based real-time data for precipitation and minimum and maximum temperatures for the regions of Pakistan have been utilized for the recent 30 years, that is, 1991–2020. This data set has been accessed from Computerized Data Processing Centre (CDPC) of the Pakistan Meteorological Department (PMD). The data for wheat crops has been taken from the National Agromet Centre (NAMC) of the Pakistan Meteorological Department (PMD) and the Agriculture Department of Punjab, Pakistan.

Primarily, the climate data for the whole country has been divided into 11 agro-meteorological regions. These regions are as follows: Potohar Region (the northern part of Punjab), Central Punjab, Southern Punjab, Upper Sindh, Lower Sindh, Northern Baluchistan, Southern Baluchistan, Lower Khyber Pakhtunkhwa (Lower KP), Upper Khyber Pakhtunkhwa (Upper KP), Gilgit Baltistan (GB), and Azad Jammu and Kashmir (AJK). Next, the data has been organized by seasonal patterns. A seasonal-based proportion of rainfalls for all the regions has also been calculated for a better understanding of the regional climatology (Fig. 2). Based on local climatology, the data has been arranged into four basic seasons, which are summer (May to September), winter (December to February), spring (March to April), and autumn/fall (October to November). However, the primary seasons are categorized on the basis of their importance for some particular crop season. Therefore, here in this study, we are considering summer and winter as primary seasons, based on their respective association with the Kharif and Rabi seasons. For the purposes of data analysis, the simple linear trend technique has been adopted. The rainfall has been discussed for each agro-climatic region, but the day/night temperatures are analyzed only for the major agricultural regions of Pakistan, that is, the plains of Punjab and Sindh.

3 Technical Analysis

In the agricultural perspective, both the quantity and the distribution of rainfall has great significance for a particular crop season. The distribution has more importance for soil with a lower water-holding capacity and at significant phenological stages of crops (Pratley 2003). The meteorological conditions play a major role in the growth of agricultural products, and their significance has become more vital at the particular stages of the crops, orchards, or vegetables. Rasul and Kazmi (2011) stated that during the cropping season "Kharif" (April/May to October/November), some major crops, including rice, sugarcane, cotton, and maize, are cultivated; therefore, lesser rainfalls produce negative impacts on local agriculture as well as the national economy. Similarly, the Rabi crops, such as wheat, sesame, and grams (October/November to April/May), are affected due to lower rains. Moreover, especially the rains during winters (December to February) would be particularly

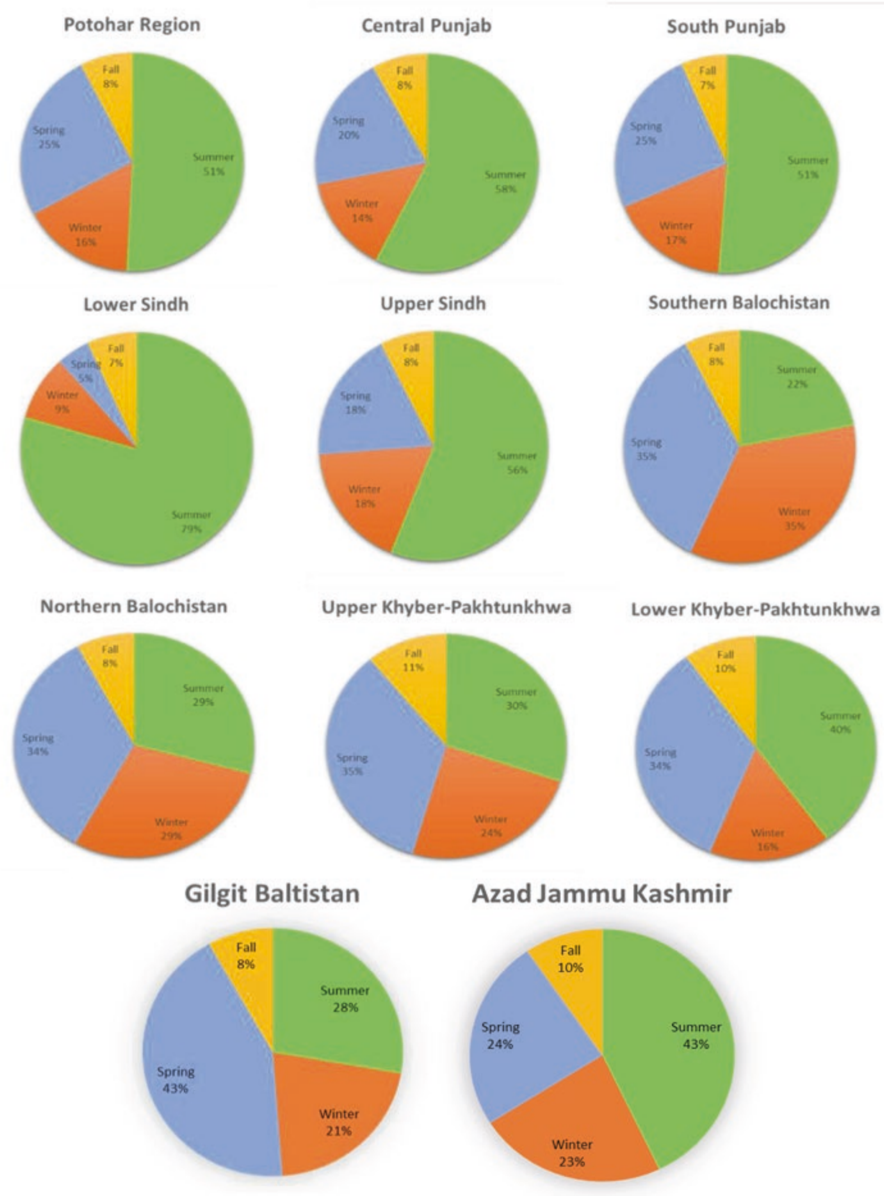

Fig. 2 Seasonal Proportion (%) of rainfall for all the agroclimatic regions of Pakistan. (Based on data for 1991–2020)

damaging for the Rabi crops. With regard to these facts, the rainfall and day/night temperatures for summer and winters are more focused in the following discussion. Also, each agro-climatic region has distinctly been analyzed to explore the real-time local conditions.

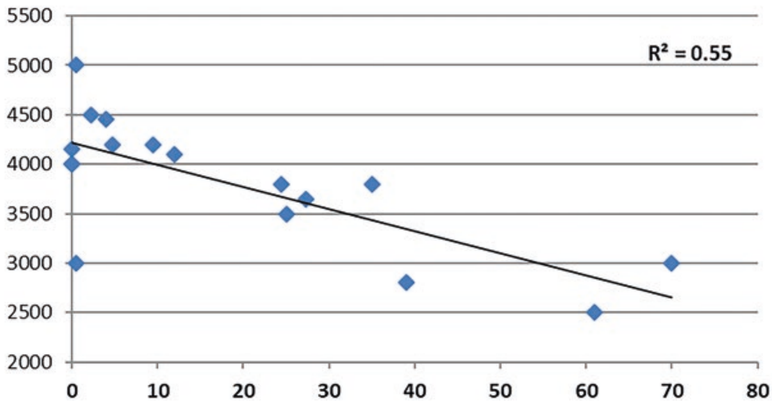

Fig. 3 Rainfall (mm) during second decade of January versus wheat yield (Kg/Ha) obtained for the period 1994–2011. Linear trend has been shown as straight line. (Rasul and Kazmi 2013)

Percentage distribution for all four climatic seasons is shown in Fig. 2. The data analysis for all the regions, with the exception of Gilgit Baltistan, reveals that summer covers the major proportion of the rainfalls followed by the spring season. And winter is very important for wheat, which was the third most important crop. Moreover, fall or autumn season (October to November) recorded the lowest rainfall. This provides favorable conditions for the Kharif crops, which are at harvesting to post-harvesting stages in most of the major agriculture plains. However, this is the time for the sowing of Rabi crops, which are affected by lower rains. In particular, at this time wheat is cultivated all over the country (Kazmi and Rasul 2012), and rainfall at each important stage is of considerable importance for the rainfed areas such as Potohar (Aslam et al. 2004; Rasul and Kazmi 2013). In rainfed areas, the timing and intensity of rainfall are most important for a crop's growth, and can determine the success or failure of a crop (Rashid and Rasul 2011; Rasul and Kazmi 2013; Fig. 3).

On the other hand, the quantity of rainfall is important to encouraging the normal growth of an agriculture crop. Summer receives the highest rainfall in most parts of Pakistan, but it's very much dependent on the El Niño-Southern Oscillation (ENSO) conditions (Rasul and Kazmi 2013). Moreover, the winter rainfall has also been badly affected because of the impact of La Niña. Climatic data shows that the strong El Niño from 1997 to 1998 produced the history's worst drought situation in Pakistan for succeeding period of more than 4 years. On the other hand, in the spring season, abnormally heavy downpours, along with hailstorms on the plains of Punjab, have disrupted the harvesting activities and damaged the standing crops in the particular areas (Dawn 2020).

Figure 4 shows the percentage departure of seasonal rainfalls for the agro-climatic regions of Punjab and Sindh, the major agricultural plains of the country with the exception of Potohar, which is a sub-mountainous and rainfed area of Punjab. Generally, the summer and winter rains, taken here as primary seasons, have recorded no major changes in recent times. However, in the case of lower Sindh, there seems a considerable decrease for winter rains. By contrast, the

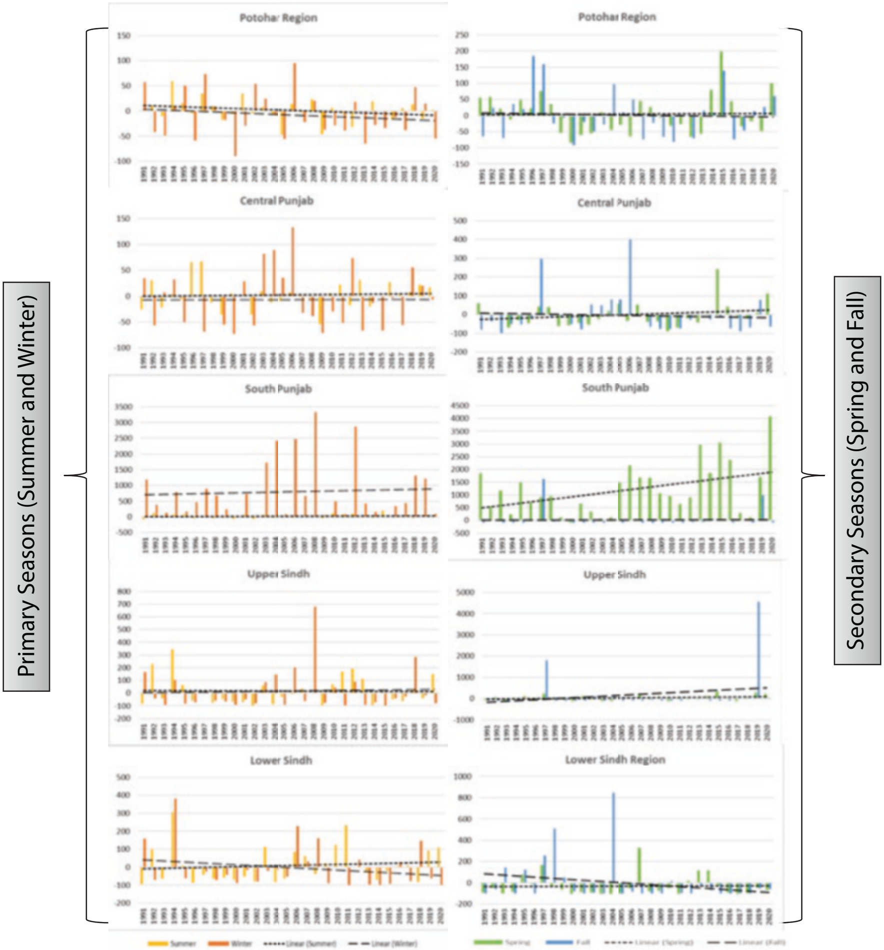

Fig. 4 Percentage departure of seasonal rainfall (% age anomaly from the normal values) for agro-climatic regions of Punjab and Sindh, the regions known as the major agricultural plains of Pakistan (except Potohar region), for the period 1991–2020

secondary season rainfalls also have no considerable change, with the exception of South Punjab (increase) and Lower Sindh (decrease).

Baluchistan, Khyber Pakhtunkhwa, Gilgit Baltistan, and Azad Jammu Kashmir are the mountainous regions mainly known for the orchard-producing areas of Pakistan. But there are plains in upper Khyber Pakhtunkhwa particularly, where the agricultural crops have been cultivated through flood irrigation. Further, most parts of southern Baluchistan are deserts. Fig. 5 depicts that during the primary seasons, these agro regions have a slightly decreasing trend for rainfalls. This decline is more prominent in the case of Southern Baluchistan during the winters. There is, however, no large change for seasonal rains during the secondary seasons, that is, spring and fall except for GB and AJK.

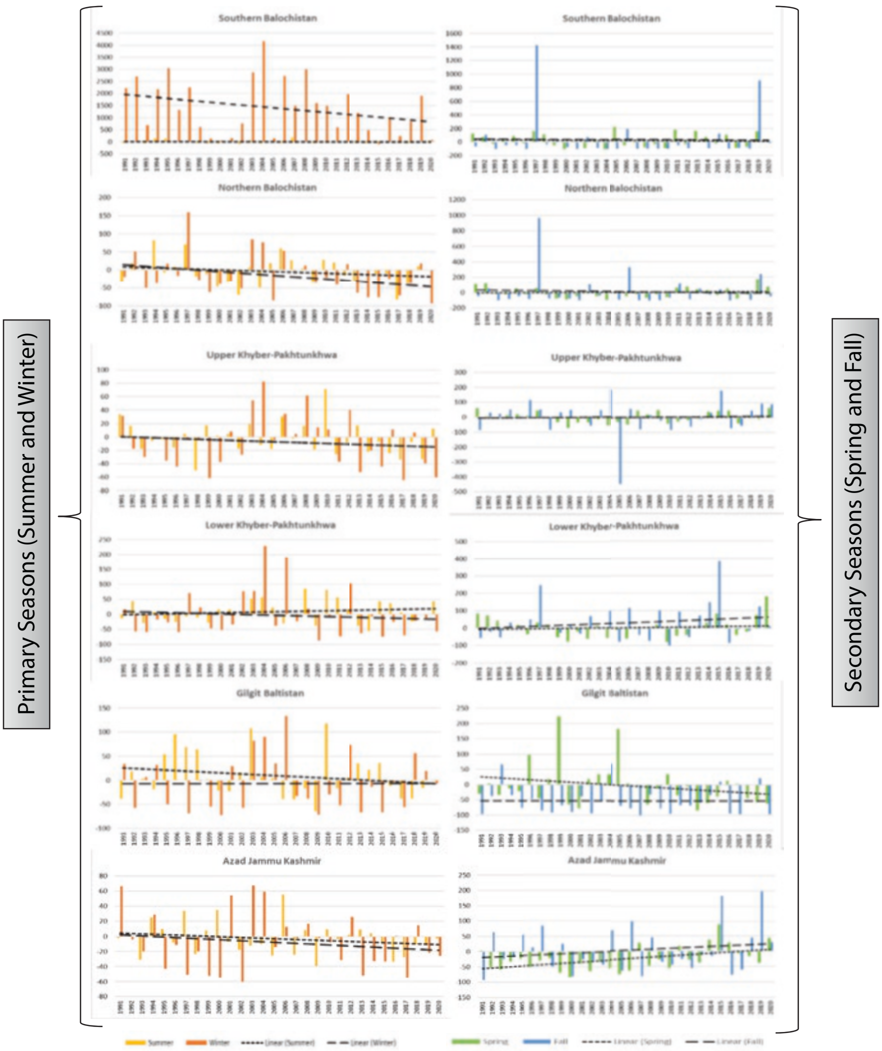

Fig. 5 Percentage departure of seasonal rainfall (% age anomaly from the normal values) for agro-climatic regions of Baluchistan, Khyber Pakhtunkhwa, Gilgit Baltistan, and Azad Jammu Kashmir, for the period 1991–2020

4 Importance of Air Temperature

In addition to rainfall, there are several other climatic features that affect the crop production, including the temperatures, relative humidity, wind, etc. (Rasul and Kazmi 2013). The minimum temperature for the major agricultural plains of Pakistan has shown an increasing trend for all the climatic seasons, with the exception of central Punjab (Fig. 6). In particular, in southern parts of Punjab and upper

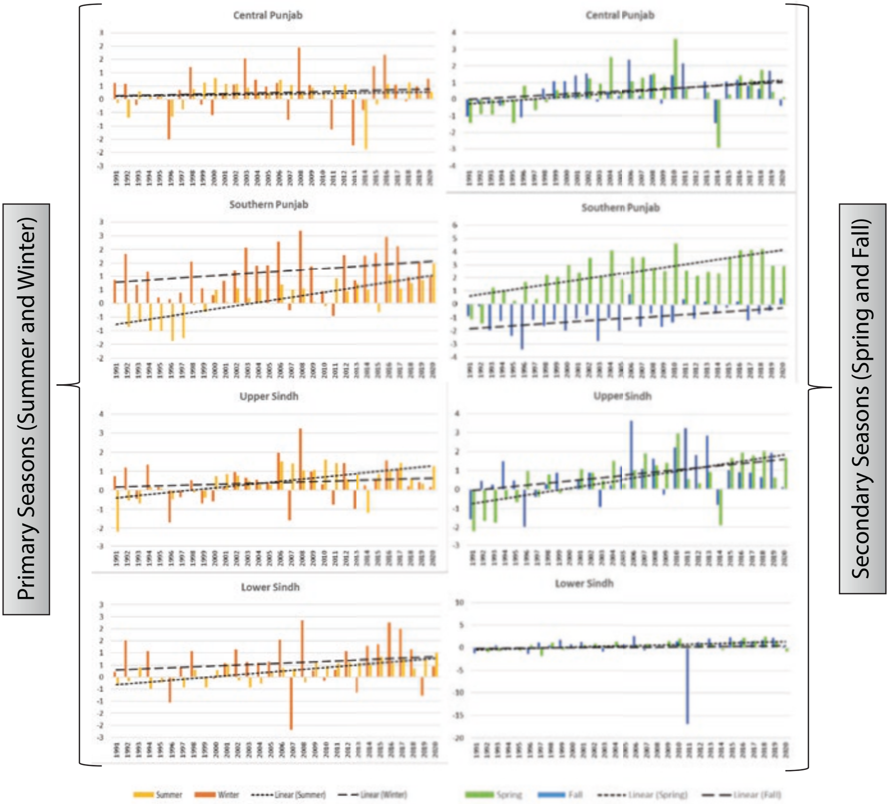

Fig. 6 Minimum temperatures for climatic seasons of the major agricultural plains of Pakistan (plains of Punjab and Sindh), for the period 1991–2020

Sindh, the average temperatures at night have become warmer in recent decades. These particular areas are already facing issues of increasingly dry and hot conditions. Therefore, warmer nights would have adverse impacts on the growth of agriculture crops in terms of early maturity and increased demand for water.

Maximum temperatures have comparatively different trends for the major plains of the country. It revealed that summer and winters are becoming slightly colder in terms of day temperatures, except for Sindh. However, the spring season has exhibited a warmer trend for all the specified regions of Punjab and Sindh. Spring (March to April) covers the maturity stages to harvesting period for the wheat crop in most of the plains of Punjab. Therefore, if both day and night temperatures are increasing (Figs. 5 and 6), then in turn related terms such as heat units and reference crop evapotranspiration (ETo) would also become higher. Consequently, during the final stages, wheat and the final production may be affected (Rasul and Kazmi 2013) (Fig. 7).

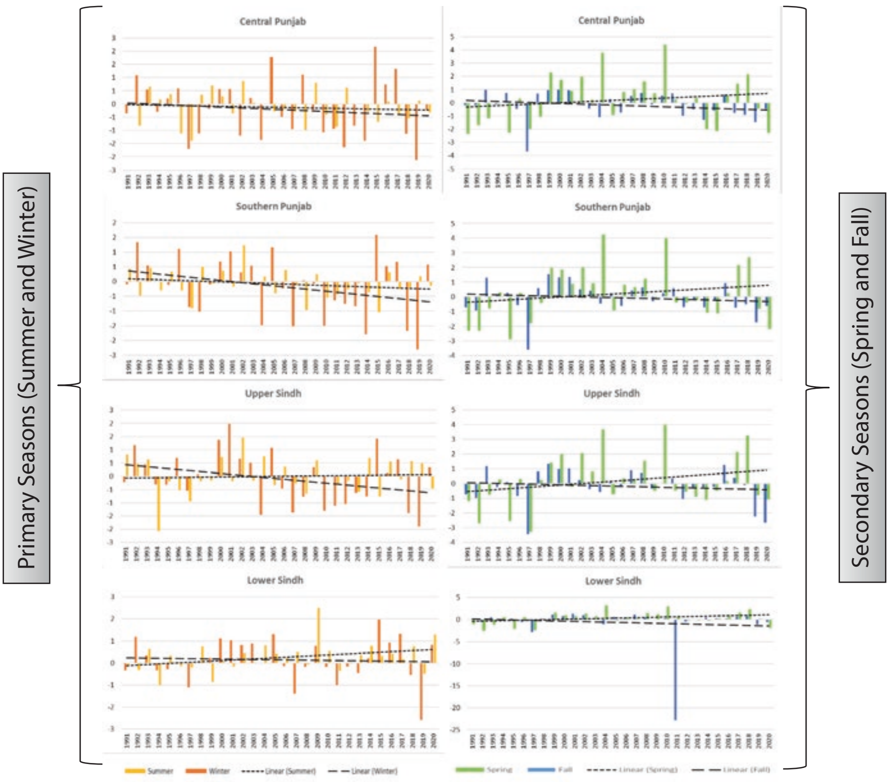

Fig. 7 Maximum temperatures for climatic seasons of the major agricultural plains of Pakistan (plains of Punjab and Sindh), for the period 1991–2020

5 Conclusion

Climate change has become the major challenge for the agrarian countries with lower levels of infrastructure. Accordingly, the global economy would be affected in a broader perspective (Keane et al. 2009). Agriculture production in South Asian countries such as Pakistan has been suffering due to issues related to climate change, including heat stress, and extraordinary levels of rainfall, accompanied by winds, storms and hailstones (PES 2021). The variable climate is modulating the rainfalls over the Punjab plains of India in ways that are proving erratic and presenting considerable challenges for the wider scientific community (Met Monograph 2020). The percentage distribution of local climatic seasons shows that the summer accounts for the major proportion of the rainfalls, followed by the spring season. The winter, that very important season for wheat and rest of Rabi crops, comes third. In recent years, the plains of eastern Punjab have been afflicted by heavy rains and hails, which has caused substantial damage to wheat and the rest of crops in the field (Dawn 2020).

Further, the temperatures are increasing for summers and winters in the major agricultural plains such as are to be found in South Asia. These areas are already experiencing dry and hot conditions, in turn exaggerating the water requirements for standing crops. Keane et al. (2009) stated that climate variabilities may immensely affect the local agriculture of those developing countries already facing the challenges of fewer crop options. According to the World Meteorological Organization (WMO)'s projection, the world is moving toward hotter, drier, wetter conditions. Therefore, agricultural scientists have to explore new varieties, especially for staple foods, to cope with the food crises in the developing countries. It is now time to achieve collective efforts over the globe by following the climate-smart agriculture program of the Food and Agriculture Organization (FAO) to minimize the effects of climate change on the agricultural sector.

Acknowledgement The authors are highly grateful to Miss Beenish Nazakat and the rest of the technical staff working at NAMC (PMD) for the data compilation and graphics. In addition, they are grateful to the administrative heads of CDPC and NAMC for the provision of data to proceed with this study.

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Nutrition-Sensitive Climate-Smart Agriculture

Tefide Kızıldeniz, Rumeysa Ceribas, and Muhammad Yasir Naeem

Abstract Adults and children continue to suffer from malnutrition and hunger in emerging nations, which hinders their productivity, growth, and development. Health and adequate nutrition intake throughtout the life cycle of individuals, especially at the earlier stage of the childhood—while the body is in its developing phases—remains essential. It is still a problem in many underdeveloped and emerging nations to ensure that people have food available to them that is secure and sufficient and satisfies their nutritional and personal choice needs. Still, nutrition security for providing diversity and nutritious food in sufficient quality and quantity is another concern. Agriculture as a component in supporting food security of indivuduals has a fundamental significance in human nutrition besides of being a basic and important livelihoods activity. Nutrition-sensitive approach is focused on the effects of fundamental factors of nutrition. This approach together with agriculture aims to place food strengthening, dietary diversity, and nutritionally rich foods at the center of eradicating malnutrition and micronutrient insufficiency in agricultural development and is called as nutrition-sensitive agriculture. However, accessibility and availability of both dietary diversity and nutritionally rich foods are much more limited by environmental changes induced by climate change effects, especially on agriculture and consequently on food and nutrition safety. Consequently, it leads to undermine current endeavors to climate resilience and coping strategies. As a coping strategy, climate-smart agriculture approach aims to reorient and modify agricultural systems to efficiently and influentially improve progress and provide food safety under the changing climate. This approach enables the buildup of innovations,

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_5

adaptation, and mitigation measures with consideration of locally centered scope in addressing climate change. Therefore, under the circumstances of changing environment and highly fragile nutrition conditions, these two approaches are deeply needed to integrate. Agricultural services can be adapted to more nutrition and climate sensitive by advancing their scope or the capability of extensions.

Keywords Climate change · Nutrition-sensitive agriculture · Nutrition security · Nutrition-sensitive climate-smart agriculture · Malnutrition

1 Climate Change and Nutrition-Sensitive Agriculture

Agriculture is inherently affected by climate change and also susceptible to other circumstances worldwide. The following issues are caused by climate change: emissions of greenhouse gases, which are expected to have a direct impact on crop production systems for food and forage; changes to crop production systems have an impact on human and animal health; and changes to the pattern and equilibrium of commercial food and other products in the agricultural system. The issues discussed above are dependent on the cycle of global warming and other factors that alter patterns of precipitation, and they will vary depending on where they occur. However, reducing such influences has a significant direct impact on the physiology of crops grown for feed, food, fiber, and fuel as well as other common effects on the diseases and other pests of livestock animals and crops (Von Braun 2020). An expert from the World Health Organization (WHO) released a statement in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) that details the harmful effects of climate change on human health, including changes in temperature, the impact of rainfall on agricultural production, food security, and malnutrition in developing nations. In order to combat malnutrition and micronutrient deficiencies, nutrition-sensitive agriculture combines foods that are high in nutrients and takes a nutrition-based approach to agricultural development and dietary diversity (Tirado et al. 2013).

A two-way approach to maintain nutrition and food security can reduce vulnerability, make it resilience, and secure nutrition under climate change effects. Nutrition-sensitive agriculture should be clearly stressed in resilience of climate development and in adaptation of nationaldisaster risk reduction plans in vulnerable and poor countries (Tirado et al. 2013). Agricultural policy should increase the availability of nutritious foods in a diverse range (vegetables, fruits, underutilized nutrient-rich indigenous foods, legumes, animal and dairy farm products, fish, etc.). Agricultural policies should support poor folk with increasing and viabling people's skill to achieve and usage the number and variety of food for having effective and healthy lives (Tirado et al. 2013).

2 The Pathway of Climate Change Impacts from Agriculture to Nutrition

The agricultural industry is a significant part of the global economy. The economy of the United States is boosted by the crops, cattle, and fisheries that are produced yearly to the tune of more than $300 billion (Melillo et al. 2014). The agricultural and food sectors contribute more than $750 billion to the GDP when the food-service and other agriculture-related businesses are taken into account (USDA 2016). The climate has a significant influence on both agriculture and fishing. In some regions, rising temperatures and CO_2 levels can improve agricultural yields. The availability of water, soil moisture, nutritional levels, and other factors must also be satisfied in order to reap these benefits. Food safety may be at risk as a result of changes in the frequency and severity of floods and droughts, which might provide difficulties for ranchers and farmers (Ziska et al. 2016). The habitat limits of many fish and shellfish species are projected to change as a result of increased water temperatures, which might disturb ecosystems. Overall, climate change may make it more challenging to cultivate crops, rear livestock, and catch fish in the same locations and ways as in the past. However, production will decrease if the higher temperature exceeds the crop's optimal temperature (Melillo et al. 2014).

Increased CO_2 has been linked to lower protein and nitrogen levels in alfalfa and soybean plants, which leads to a decline in quality (Melillo et al. 2014). Crop growth may be hampered by more severe precipitation and temperature. Extreme weather conditions, particularly droughts and floods, can damage crops and lower harvests. This has an immediate impact on human health and might endanger it. Due to growing insect pressures and declining pesticide performance, increased pesticide usage also poses a concern to human health (Ziska et al. 2016).

However, during the past 30 years, climatic influences have already reduced global agricultural production by 1–5% per decade compared to what would have been achieved. Particularly, maize and rice have been negatively impacted since they are cultivated in tropical countries (Porter et al. 2019). Some projections indicate significant declines in forage availability in some regions and widespread adverse effects on fodder quality and livestock productivity, with significant effects on food security and incomes (Thornton et al. 2018).

3 Crosscutting Approach on Climate-Smart Agriculture and Nutrition-Sensitive Agriculture

The concept of climate-smart agriculture (CSA) is a united attempt to pointing the assembled difficulties of food safety and changes of climate. CSA aims to boost food safety by increasing productivity of agriculture and incomes (McNunn et al. 2020). Worldwide agricultural yield may decrease by 2% per decade until 2050 (grounded on these projections of fiber cereal outputs and livestock production);

currently, worldwide food request will have boosting with 14% by 10 years (IPCC 2014). In fact, a growing number of estimates consistently suggest that the impacts of climate change will result in improved conditions for agriculture in higher-latitude areas, while the subtropics and tropics will experience smaller positive terms and decreased outputs, especially of maize, rice, and wheat (Zabel et al. 2014).

Alters in rainfall and temperature, insects, and disease of crop environments are going to impact efficiency of agricultural in various paths. Healthy diet that adds sufficient, variable, nutrition-rich foods and safe is a necessary building block for physical and brain development on children (Black et al. 2008). Low harvests combined with population growth, declining urbanization, poverty, and rising nutrition demand in these areas are likely to increase pressure on nutrition costs and make it harder for those in need to access healthy foods, including small farmers who frequently receive the less nutrients (Nicholls et al. 2020). They control demand; enhance local food production; alter the value chain and agricultural tools; raise local, regional, and global targets for agriculture and nutrient trade; and provide better labor security systems that preserve the purchasing power of those in need in rural and urban areas. Moreover, preference wants to be dedicated for decreasing GHG emissions linked with nutrition production technology used in nutrient marketing, storage, transportation, and easing exclusive ownerships hedge, which will preserve nutrition materials for entire consumers, supporting major consume and understanding of environmental inclusions of nutrient selections (with emphasize apart from latent worths of distribution, manufacturing, cultivation) (Garnett 2011). Nutrition-sensitive nourishment framework that may point primary agents of undernutrition all throughout chain from nutrition manufacture, by commerce and working, to market (Ruel et al. 2013). Yet, experimental proof based on "what can work" for adjusting as well increasing nutrition system to deal with change of climate is yet narrow, much for proof of how rapidly and how much climates are alternating is comparatively latest. Governments all around the globe must prioritize a rigorous assessment of how local climatic conditions are evolving, as well as the impact of programmatic and regulatory initiatives to make various components of the nutrition system far more adaptable to actual and planned modifications. There are already excellent examples of how nutrition frameworks may be constructed to be far more resistant to modern day risks. For instance, it has been noted that researchers are constantly advancing and promoting the use of crops that are tolerant to drought stress, such as varieties of wheat, rice, and legumes like peanuts that are resistant to pests and heat-tolerant animals (Mottaleb et al. 2012; Thornton and Herrero 2014). Other investigators search for rise in the content of nutrient (vitamins, minerals) by ensuring that stamped and non-stamped crops are produced intensively more nutritious; the crop often benefits crop vitality for last consumers (Welch and Graham 2004). So, nourishment boosting policy interventions require to contain just diversity of manufacture in agriculture, but same time developed marketing and commerce which assists reach to both nutritive foods and growing commercial nutritious food crops and their consumption for diversifying the diets. Notice in nutrition cost policies to impetus that can stimulate major presence and possibility to access nutrient-rich foods to every user could also have possible worth.

4 Agricultural Extension Services for Nutrition-Sensitive Climate-Smart Agriculture

Climate-intelligent farming is an attempt by the United Nations' Food and Agriculture Organization (FAO) to support adaptation of food system and mitigation for climate change effects. Until now, those activities have concentrated on elevating productivity of agriculture and revenue, building and adapting resistance to climate change effect (FAO 2013). Diversification of crop using variations vernacularly adapted is commonly supported as a tactic, which supports the adaptable capability in most systems of food (Thornton et al. 2011; Davis et al. 2012; Müller et al. 2011; Waha et al. 2013; IPCC 2014). Few schemes began to construct flexibility to weather instability into producing of farm systems. For instance, "*Adaptation for Smallholder Agriculture Programme in Bolivia*" has applied local information concerned to climate change adaptation for helping farmers, one of diversities that could be grown at higher or lower altitudes. Bolivian and Sahel agroforestry projects are promoting the production of nonconventional trees that are volatile to heat and drought stresses. These include Baobab (*Adansonia digitate* L.), whose fruit and leaves tender lot high-grade nutrition, and *Vitellaria paradoxa* that ensures fruit in the angular period for users (Business 2014). Variety of diets symbolizes a basic view of dietary gradequality since the utilization of poly kind of foods usually mirrors a diet with higher grade that is most probably to fulfil the users' nutrient requirements (Bhutta et al. 2013). This makes the global food supply more vulnerable to threats including illnesses, weather-related effects, and pests, which are likely to increase as a result of climatic changes (Khoury et al. 2014).

5 Adapting and Building Resilience to Climate Change for Food and Nutrition Security

The food system to support nutrition-boosting diets and resilience involves more than just producing more of the same. Major outputs are required, with a greater diversity, to improve the sustainability of food systems (FAO 2013). The applications also help to reduce GHG emissions in each unit of nutrition. Improved species/varieties may be promoted for nutrition-intense non-staples such as vegetables and forage foods. Conservation and biodiversity enhancement can also foster variability in less-conventional methods of agricultural production. When farm animals' output is typically source-intensive (with high costs of water and other natural resources) and contributes to climate change through greenhouse gas production, large yield in systems can reduce animal numbers held while increasing yield and quality per unit (Friel et al. 2009). As a result, increasing the diversity of livestock and crops, as well as adopting more heat, water scarcity, pest, and/or disease-resistant types, might be beneficial to climate-resilient agriculture while also increasing consumer diversity (if those nutritions achieve markets at fair prices to the needy) (Williams et al. 2007). Other activities are required to reduce the costs and economic activity of innovations in food conservation for the extension of post-harvest preservation and decreased perishability, cultivation (with the goal of maintaining nutrition and product qualities), marketing, and additionally decreasing carbon emissions associated with value-chain actions wherever possible. Particular crops, including rice beans, maize, and peanuts (Ristaino et al. 2021), which have low resistance to heat/water stresses, are more probably to be broken or contaminated via pests, molds, and disease, with reflections on food quality and also safety (Rosenzweig et al. 2001; Tirado et al. 2010). A focus on reducing post-harvest damages, advanced preservation to maintain food quality and safety, improved infrastructures for paths, information systems, and cooling, which can decrease losses of products that are high in nutrients and perishable, as well as interaction with the special sectors, is necessary for preventive nutritions in food supply and rising resilience to climate change (Cornelsen et al. 2015). According to knowledge of significant food cost impacts over the past 15 years, an increase in interest in the overall consumption of nutrients that only provide energy in the form of calories has been seen in front of a decrease in the purchasing and consumption of nutrient-dense foods like vegetables, meat, dairy products, and fruit in most statuses. A focus on reducing post-harvest damages, better storage (to maintain food security and quality of goods), advanced infrastructure (paths, knowledge systems, cooling) that can decrease damages of highly nutritious perishable products, and interaction with special sector is necessary to maintain nutrients in the procurement of food and increasing climate change resilience (Pingali 2015).

6 Gender Dimension and Social and Behavior Change for Nutrition-Sensitive Climate-Smart Agriculture

Agriculture is a productive sector for both genders. But due to traditional gender-set discrimination, women have less prerogatives, rights, and donations. Input, consumption, and management of efficient sources and services, such as inputs, land, credit, water, technology, extension, education, information, and other rural consulting services, markets, weather, and climatic expertise, provide more problems to women than to males. This affects their susceptibility to climatic hazards and capacity for adaptation. Gender-specific changes in climate-smart agriculture are measured by the extent to which women may equally access sources like livestock or land services, businesses, and job opportunities (Nelson and Huyer 2016). However, the current challenges that women confront are heightened by climate change. The relationship between gender inequality and climate change has an impact on many different levels.

7 Nutrition-Sensitive Climate-Smart Agriculture Best Practices

When advocating for and deciding on methods for climate-smart agriculture, the information gathered during a gender analysis is invaluable. The important question is: How can nutrition-sensitive climate-smart agriculture applications be defined, designed, and applied in a path that gets into count for eliminating disparities between man and woman and contribute to the gender equality promotion? This is necessary to ensure that the findings for gender analysis are used in climate-smart agencies. In order to adopt climate-smart agriculture applications in special, a possible implementation's notional additive to the three aims of adaptation, mitigation, and food safety requires also the importance to its gender effect. Significant field research in South Asia and Africa, reached over program experience and professional know-how, should create the conditions for a conducive development framework. The latter will serve as a sample for further work. A local team will be engaged over feasible climate-smart choices complemented and integrated by their gender-concerned features suitable to context-centered needs and priorities. (World Bank, FAO and IFAD 2015; Duffy et al. 2017). Climate-smart projects that unite gender issues along the cycle to provide certain wants and primacies of both man and woman should be planned and efficiently pointed (Babugura 2021).

8 Conclusion

Nutrition-sensitive agriculture (NSA) programs are proven to enhance a range of nutrition outcomes in both mothers and children by new data from thorough impact assessments. Programs should also include actions to improve health and water, sanitation, and hygiene (WASH) practices and should provide specially formulated fortified products to address children's high nutrient requirements in areas where access to nutrient-rich foods is restricted and greater benefits for child nutrition outcomes (e.g., dietary diversity, nutrient intakes, Hb/anemia, diarrhea, and weight-for-height z-scores (WHZs)) are achieved. But despite ongoing attempts to improve the design, scope, execution, and assessment of NSA programs, effects on stunting have not yet been shown. We come to the conclusion that while adding multiple interventions to NSA programs that target a wide range of direct and underlying factors affecting children's nutrition (such as income, food availability and access, micronutrient sufficiency, gender equity, and knowledge, practices, and use of services related to nutrition, health, and hygiene), it is insufficient to achieve stunting impacts in the typical 2- to 4-year time frame used for immunization.

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Food Security Issues in Changing Climate

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Abstract The security of food is extremely crucial for humans all around the world. The worldwide climate is continuously changing, and the major cause of the temperature rise is industrialization. Moreover, it is also influencing the food system in different ways, from direct impact on crop production to changes in markets, food prices, and infrastructure in the supply chain. Precipitation change may lead to drought or flooding, and warmer or colder temperatures may alter the growing seasons. In the current century, our planet's average temperature is preceded to surge from 2 to 4.5 °C. For food security, the relative importance of climate change varies from region to region. For the next 50 years and beyond, global food safety will remain a global concern. In several regions of the world, crop yield declined mainly

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_6

due to poor research infrastructure and facilities related to coping with the climate change disaster. Rainfall shifts and temperature fluctuations in large numbers are threatening agricultural development and have increased the vulnerability of livelihoods of people dependent on agriculture. Climate change interferes with food markets, posing population-wide food supply threats. Threats can be minimized through the increase in farmers' adaptive ability and by increasing the resilience and efficiency of resource use in agricultural systems. While agroecological approaches (such as crop diversification, low-till farming, green manures, organic fertilizers, nitrogen-fixing bacteria, biological pest management, rainwater collection, and raising crops and livestock in ways that store carbon and preserve forests) are promising to boost yield, food security may dramatically improve in developing countries by growing policy and investment reforms. Food quality, access, and availability may all be impacted by climate change. Adaptation must promote the management of all food security levels, both urban and rural, from the farmer to the customer. Measures from the community to the international level have to be participatory. Moreover, many individual endeavors provide inspiration and useful methods, but the maintenance and improvement of food security can all be hindered by institutional, economic, and environmental factors. It will be necessary to develop innovative approaches to food production, delivery, and storage.

Keywords Crops · Climate change · Adaptation · Yield loss · Food quality · Management practice

1 Introduction

Devastating environmental changes have had a severe influence on natural systems, human health, and agricultural productivity (Arunanondchai et al. 2018). With the increase in the population of the world, food consumption is also increasing. The access of water, fertility of soil, and contamination in soil or air have a significant impact on agricultural output (Noya et al. 2018). Abiotic stresses have both direct and indirect impacts, and the adverse consequences on the productivity of plants are increasing in intensity when environmental circumstances change abruptly. Extensive use of fossil fuels and deforestation have increased the levels of CO_2 from 280 nmol^{-1} to 400 nmol^{-1} in the air. It is predicted that CO_2 concentrations would double, reaching 800 mol^{-1} to the end of this century. Hazardous gas emissions, notably CO_2 emissions, are the key causes of the rising global average temperatures and also the greenhouse effect (Vaughan et al. 2018). The frequency of stress episodes, their impact on daily life, and crop loss are all used to measure the effects of climate change and environmental variability (FAO, IFAD, UNICEF, WFP and

WHO 2017). In developing nations, agricultural productivity is mostly affected by harsh climatic circumstances; hence, high temperatures and excess CO_2 buildup obligated scientists to find new procedures to deal with fewer imminent obstacles (Rosenzweig et al. 2014). It is necessary to create new climate-smart agricultural cultivars to overcome these obstacles and guarantee food security (Wheeler and Von Braun 2013). Abiotic stressors have a substantial effect on plant development and output. Plants are frequently subjected to a variety of stressors in their natural environment, including waterlogging, heat, drought, salt, and cold (Abbas et al. 2017; Fahad et al. 2017; Saud et al. 2017; Zia et al. 2017). UV-B, floods, gas emissions, light intensities, and physical and chemical variables all contribute to increased stress (Suzuki et al. 2014).

In the twenty-first century, it is predicted that the average temperature of the globe will rise from 2 to 4.5 °C. According to the intergovernmental panel for climate change (IPCC-2014), the era between the nineteenth and twenty-first centuries had the highest warming (Pachauri et al. 2014). Extreme rainfall can cause floods, whereas a scarcity or entire absence of rainfall over an extended time causes drought pressures (A. Khan et al. 2016). The industrialization of the world is one of the main factors contributing to the ongoing changes in the climate. According to projections, extreme weather will increase the frequency of global warming, which will eventually destroy the world's environment (Kanojia and Dijkwel 2018).

Extreme environmental circumstances have affected all living organisms, and it includes plants, animals, fish, and humans all over the world. Concern about the threat to global climatic conditions has grown since agricultural production may be threatened by changes in many environmental factors, jeopardizing food security. Recent studies show that industrialized nations are more susceptible to climate change (8–11%) than developing nations (Altieri and Nicholls 2017). The biggest issues faced by humanity in twenty-first century are food shortage, hunger, and climate change. Malnutrition affects 815 million people, making it difficult for sustainable development projects to accomplish the global objective of eradicating hunger by 2030 (Richardson et al. 2018). The unfavorable weather has a substantial effect on agricultural productivity and food security. The output of main crops has decreased as temperatures have risen across the planet (Tito et al. 2018). Reduced agricultural yield is hampering food security, especially given the world's rapid population growth (Rogelj et al. 2016).The population is predicted to reach nine billion by 2050, with food demand increasing by around 85% (Faostat 2017). Current agricultural practices with little variation and high input concentrations, as well as unpredictable crop output because of the environmental changes in the crops, worsen climate consequences (Reckling et al. 2021). Enhanced and infrequent patterns of rainfalls and drought, salt, increased or varied temperatures, and pest and insect assaults are expected to reduce crop yield, raising the risk of famine (Dhankher and Foyer 2018). Rainfall has also contributed to crop adaptability, in addition to temperature variations. Currently, the primary goal is to reduce the strain on food security (Campbell et al. 2016).

2 Climate Change, Effect on Plant Phenology, and Yield

Infrequent and heavy rainfall and drought, temperature variation, salinity stress, and insect pests are expected to reduce crop yield, raising the risk of famine (Dhankher and Foyer 2018). Increased temperature disturbs the ability of crop adaptation to the changing climate. Currently, the primary goal is to reduce the impact on food security. Drought and high temperatures are major stressors that have a significant influence on grain quality, and Rubisco, the primary enzyme of photosynthesis, is disturbed if the temperature rises beyond 3.5 °C, thus stopping the photosynthetic process. Heat stress has a deleterious effect on antioxidant enzymatic activity in *Zea mays* L. (Daloz et al. 2021). However, temperature extremes caused by climatic changes have a substantial impact on wheat output in many countries, potentially reducing crop yield by 8% for each degree Celsius increase in temperature (Asseng et al. 2015). It is generally known that heat stress and drought together have a negative impact on the yield of crops including barley, sorghum, and maize. It was shown that the blended effect of drought and heat stress had greater negative results than individual stress. *Leymus chinensis* was exposed to the combined stressors of dryness and heat, and the function of Photosystem II (PSII) was disturbed (Xu and Zhou 2006). In some crops, fluctuating temperature and water scarcity are influencing the reproductive stage of plant development. In addition, water stress has been shown to harm flower initiation and inflorescence in wheat (Amin et al. 2017a; Shakeel et al. 2017; Jabran et al. 2017; Vickers 2017; Ahmad et al. 2017). Similarly, a temperature rise of roughly 30 °C during floret formation might result in sterility in grains. However, wheat and rice had a 35–75% drop in grain set owing to water shortage during the meiotic period.

Drought stress significantly disrupts the fertilization and anthesis processes in rice. Due to the lack of water, the harvest index is decreased to 60%, resulting in a lower grain set. In West Africa, the large drought periods in the 1980s in El Niño years drastically impacted cocoa yield (Ruf et al. 2015). Climatic changes are expected to lower the production of agriculture by 25.7% by 2080, with maize being the most affected crop in Mexico. The North German Plains were the subject of research using ECHAM6 climate data for the time spans of 1981–2010 and 2041–2070. The findings revealed that if winter wheat yields are to be consistent, the accessibility of water must be ensured (Nasim et al. 2016b, c; Zhu 2016), performed a research to check the influence of climatic changes on main crop yields, and discovered significant production losses of 6%, 3.2%, 3.1%, and 7.4% in rice, wheat, maize, and soybean, respectively. Novel genetic inventions are facilitating climate-smart agriculture by developing crops that are responsive and resilient to climate change (Scheben et al. 2016). Wheat is subject to drought stress at all stages of development, although grain formation and reproduction are greatly significant. Production of wheat dropped from 1% to 30% during post-anthesis moderate drought stress, and this loss increased to 92% following prolonged mild drought stress throughout flowering and grain formation (de Oliveira et al. 2012). Drought has lowered the output of major cereal legumes significantly. Drought stress lowered mashbean (*Vigna mungo* L.) yield from 31% to 57% during the blooming stage, whereas it reduced output by 26% during the reproductive stage (Baroowa and Gogoi 2014; Jabran et al. 2017; Amin et al. 2017b). According to Maleki et al. (2013), drought stress has had a significant impact on soybean output, with a 42% decline seen during the grain filling stage of soybean.

It was expected that greenhouse gas emissions would rise and rapid climate shifts would occur, perhaps increasing agricultural output in North-Western Europe while decreasing crop yield in the Mediterranean region (Cramer et al. 2020). The yield of maize was boosted at an optimal temperature of 29 °C, but subsequent temperature increases harmed maize output. Similarly, yield in maize was reduced by 8.3% for every 1 °C increase in temperature over the optimal development temperature (Shahzad et al. 2021). It is found that every 1 °C rise in temperature reduced wheat output by 10%. According to another study, every 1 °C increase in temperature reduces wheat output by 3–4%. According to studies, a 2 °C rise in temperature caused a 7% decline in production, although a 4 °C increase in temperature reduced wheat yield by up to 34%. Similarly, every 1 °C increase in temperature reduced rice output by 2.6%. A 1 °C increase in temperature lowered sorghum production by 7.8%. Moreover, water scarcity is another major concern in the world's top producing countries for sorghum. It is discovered that the upper limit temperature for soybean is 30 °C, increasing the temperature to the optimal stage boosted soybean output but increasing the temperature further lowered the yield. It observed that rising CO_2 and ozone concentrations in the atmosphere increased the disease outbreak. Additionally, they also found that disease susceptibility in soybean increased with rising temperature (Cramer et al. 2020). A minor increase in temperature may increase pasture productivity in humid and temperate grassland zones but not in arid and semiarid regions (Fig. 1).

Various climate models expect that in dry areas, evapotranspiration will be high, and soil moisture will be low. As a result of climatic change, many ecological zones may become unfit for agriculture, while other regions may increase the yield significantly. Extreme fluctuation in temperature will also provide further favorable environmental circumstances for agricultural pests and insects to enhance their ability to survive at low temperatures and subsequently become more dangerous in higher temperature (Mirza et al. 2017; Hammad et al. 2017; Gillani et al. 2017). Furthermore, it is critical to note that all previous estimates for food safety and security have focused primarily on the consequences of climate change that do not account for the possibility of significant changes in the pace of climatic excesses on crop yield. They also have failed to account for rapid changes in socioeconomic position and climate, and as a result, all these factors have had a severe influence on global food security and safety. Food quality, quantity, and safety remain the most pressing issues for researchers because of the change in the climate. To evaluate food security conditions completely and scientifically, future research on the security of food will need to consider climatic changes, agricultural production, population, and supply of water.

As the Earth's temperature increases, the climate changes considerably and becomes severe on an abiotic level. Natural crop species are at danger from a range

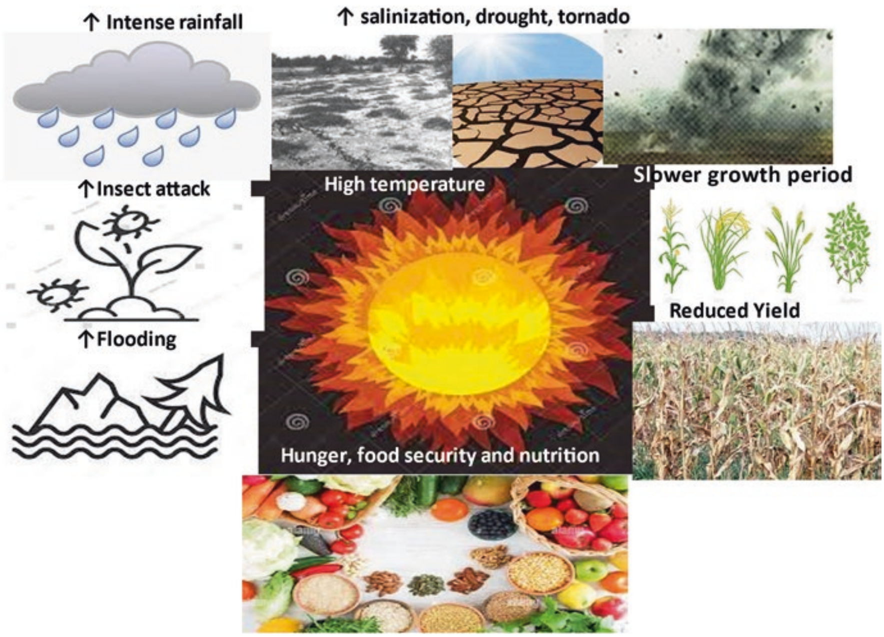

Fig. 1 Global temperature rise and its impacts on crop growth and yield

of environmental changes that are exceedingly destructive (Pereira 2016). The most frequent stressors in the field are heat and drought, both of which have a significant effect on plants. It has been noted that for normal growth and flowering, plants require an ideal temperature. Plant physiology is significantly impacted by variations in temperature (Hatfield and Prueger 2015; Mubeen et al. 2016; Rasool et al. 2016; Alghabari et al. 2016). Grain yield and production are negatively impacted by heat stress, necrosis is brought on by winter stress, and plant morphophysiology is negatively impacted by drought stress. These climatic factors have a substantial impact on plant growth and yield, which causes a large-scale chain reaction that results in morphological, molecular, biochemical, and physiological alterations (Zandalinas et al. 2018). Overall, climate change and global warming have both detrimental and beneficial consequences on agricultural products and humans.

For scientists to create stress-tolerant plants in this climate, understanding the mechanisms behind plant stress tolerance has appeared as a major challenge. To meet the world's daily food needs, it is essential to grow the key cereal crops like rice, wheat, and maize. In comparison to maize or rice, which only provide 2–3% of the world's agricultural land that is mowed, wheat has a substantially greater protein concentration: 15% per gram (Lewis 2017). Despite vast amounts of growing acreage across the world, its output has been significantly lower than that of maize and rice. Wheat productivity was expected to decrease by a reasonable amount by rising the temperature to 2 °C. According to an interrelated study on the adaptability of environment, the wheat output would be reduced by 6%. The decrease in grain filling phase owing to temperature increases is the primary cause of agricultural yield loss in changing climatic circumstances. Therefore, maintaining agricultural productivity and creating crop species that can withstand stress are major challenges in modern agriculture (Abhinandan et al. 2018).

3 Various Crop Development Limiting Factors

It is crucial to produce stress-indulgent plants and recognize their reactions to various stress circumstances to provide food safety and ecological agriculture for the globe's increasing population. Plant responses to disparate conditions of climate vary in terms of metabolism, gene expression, and physiology. Plants are suggested to be capable of sensing any alteration in neighboring environmental indicators, nevertheless (Zhao et al. 2017). Plant organs and tissues are damaged as a result of various stressors, and they react appropriately; such transcriptional reactions to several stresses differ in distinct tissues or cells of roots. The cellular signals produced by salt, drought, and chemical effluence include the creation of stress-responsive proteins, increased amounts of related solutes, and higher antioxidant ratios. They seems to be major stressors, and they cause secondary stresses, for instance, osmotic and oxidative stress (Carvalho and Amâncio 2019). Reactive oxygen species (ROS) are created as a result of elevated CO2 levels in the leaf during a drought, and these ROS cause a number of stressors in crops. Closed stomata restrict CO_2 movement in the body of leaf, and ROS are generated as a result of higher oxygen levels under dry circumstances. The frequency of membrane breakdown brought on by ROS generation interferes with plant development, photosynthesis, and respiration. Drought stress impairs several cell-building ingredients such as lipids, carbohydrates, nucleic acid, and proteins. According to current research, osmo-protectants are generated in tomato plants under collective stress conditions of salt and heat, but not under separate stressors. Another investigation indicated that the combination of heat and salt stress results in different metabolomic profiles, as determined by the statistics at molecular and physiological levels. ROS plays a vital function in the growth of the plant and is regarded as a critical subordinate indicator for metabolism in cell: a higher quantity of ROS induces cell death. Higher ROS production may result in the reduction of cell growth and sometime may lead to the death of the cell (Martinez et al. 2018). The adaptation of *Arabidopsis* to continuous water shortage was investigated at the morphophysiological and molecular levels. *Arabidopsis* taken from diverse habitats demonstrated transcriptome changes (Fahad et al., 2016a, b; Nosheen et al. 2016). Under water stress, metabolic profiling of several important plants, including rice, soybean, maize, and tomato, has been completely done. Abundant metabolomic investigations have on barley helped to better apprehend the effects of scarcity of water on the abscisic acid, oxidative stage, and free amino acids (da Silva Filho et al. 2022). Water deprivation was used by barley cultivars to investigate genetic modification on the metabolomic level during the formation of the grain phase (Hassan et al. 2017). The first metabolic signal against abiotic conditions is the suppression of protein synthesis. Abiotic stressors are also primarily responsible for posttranslational alterations and processing (Fàbregas and Fernie 2019). In coffee, water scarcity and drought stress have been researched from a variety of perspectives by including important aspects of plant physiology and biochemistry. Plants exposed to several instances of persistent drought stress have stronger photosynthetic processes than plants subjected to only one incidence of drought stress. Unquestionably, these plants exhibited advanced RuBisCo control as well as multiple enzymes involved in metabolism (Devlet 2021). The expressions of the gene linked with drought endurance were refined as a result of adaptation to varied drought dosages (Raza et al. 2019).

4 Impact on Physiological and Biochemical Processes in Plants

Plants are suffering from distinct climatic circumstances as a result of high environmental unpredictability, limiting their capacity to adapt successfully in a variety of ways. Plant migration is not a viable solution to this problem due to increased rainfall and temperature (Liliane and Charles 2020). Plant physiology changes, on the other hand, have proved advantageous in some climatic situations, although environmental unpredictability may be hazardous to plants. Abiotic stressors have had a substantial effect on plant morphological, biological, and biochemical systems. Even though plant physiology reactions are likely to proliferate swiftly in the future, with modest variations in fruiting and flowering (Jan et al. 2016). The favorable temperature for the growth of the plant is between 10 and 35 °C. Elevating the temperature to a set degree permits plants to create surplus food, while a bigger temperature rise slows plant development and reduces the photosynthesis rate to lethal levels (Ullah et al. 2022). The drought stress, which reduces cell growth, limits turgor pressure. Lack of water impairs the function of the photosynthesis enzymes, lowers metabolic efficiency, and eventually kills the photosynthesis machinery. Environmental factors cause CO_2 levels to rise, decreasing plant respiration and raising warmth. When the temperature was raised from 15 to 40 °C, the plant's respiration rate increased, disrupting the morphological traits of particular crops (Jan et al. 2017). The enzyme Rubisco is involved in the fixation of carbon and CO_2 translation into a complicated energy-rich molecule during the photosynthesis process. Rubisco is activated at an optimal temperature by the Rubisco activase by eliminating secondary metabolites (Degen et al. 2021). A modest temperature increase causes inactivation of the Rubisco enzyme, which resulted in the production of xylulose-1,5-bisphosphate, which is thought to be a repressing molecule (Fig. 2). Due to the breakdown of Rubisco activase at higher temperatures, Rubisco could not function well and could not be activated. ROS including OH, H_2O_2, and singlet oxygen are metabolic byproducts that are controlled by an antioxidant defense system. Under ideal conditions, ROS are primarily generated in small amounts, but when concentrations rise, environmental stress is triggered (Nasim et al. 2017a).

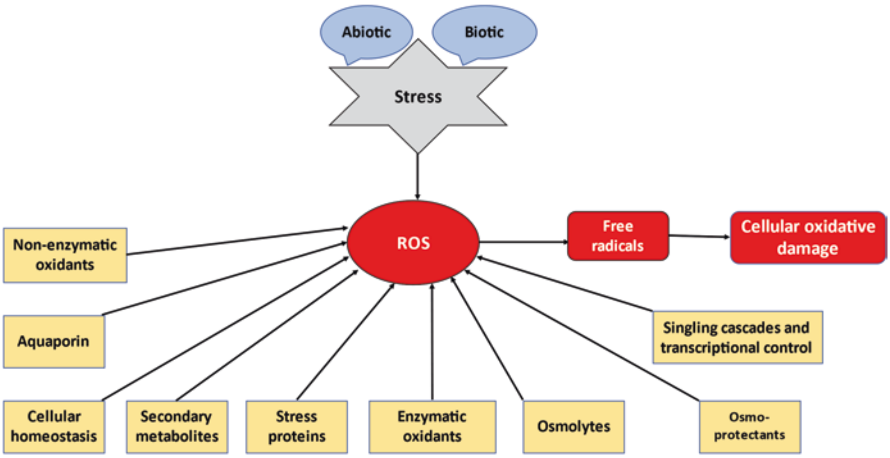

Fig. 2 Effects of different types of stresses on the cellular biochemical activities of plant

5 Application of Improved Plant Breeding Techniques

Plant breeding exemplifies dynamic approaches to crop improvement and development under a range of environmental challenges. By creating cultivars that are resistant to stress, it offers a way to potentially ensure food security and safety during periods of extreme weather change. It also helps plants escape various stressors at crucial points in their growth cycle. One of the most crucial components in defining finished inbreeding is genetic discrepancy analysis, which is used for inbreeding, polymorphism, assortment, evaluation, and recombination to get perfection in plant. A crucial tool for creating innovative cultivars focused on genetic similarity and distance is analysis of genetic divergence (Raza et al. 2018). Genetic research frequently uses landraces as a basis. For instance, a wheat landrace kept in a data bank has a greater genetic diversity and serves as a wonderful foundation for cultivars that are stress-tolerant to a variety of environmental conditions. The genomics methodologies such as marker-assisted selection (MAS) and genome-wide-related studies may be employed to generate abiotic and biotic stress tolerance cultivars employing molecular and integrated plant breeding (GWAS) (Das et al. 2017).

6 Aspects Influencing Food Security

According to European Union (EU), the food and beverage industry is losing effectiveness, which might be ascribed to shortage of openness within the system of food supply, bad interactions from business to business, a very low attraction for talented employees, and a scarcity of integration of market between EU nations (Mc Carthy et al. 2018). These problems are not limited to the EU and may be unswervingly related to the issues of security of food confronting people throughout the world. There is no single cause of the problem, which is in line with the fact that global security of food does not have any single and merely one solution. In order to pinpoint the crucial factors that will result in a solution, the section below examines that what are the main reasons of food insecurity all around the globe. Each pillar is as vital and must be treated with the same level of attention (Aborisade and Bach 2014). This pillar requires keeping a sufficient supply of food on hand at all times (Fig. 3). This pillar looks at food that is grown nearby by farmers or imported through the region's import infrastructure. Additionally, it can include the availability of food in a particular area right now as well as food aid commitments from other countries. It is also crucial to understand that possessing a lot of food won't guarantee its security (FAO 2015).

Access to food takes into account both the economic and physical availability of food. Important factors here involve a region's obtaining power and income levels (per population) in comparison to other regions. Local structures, like transportation modes and financial resources to facilitate commerce across a certain region, are also elements to consider. The management of food from a safety perspective is addressed in the utilization of food, which focuses on the entire supply chain (El Bilali et al. 2019). In primary manufacturing, distribution, secondary processing, retail, and the household, sanitation is emphasized. To guarantee that people are more conscious of the nutritional value of different meals, it is necessary to develop economical and safe food utilization as well as nutritional awareness among stakeholders. But supply and access stability are what matter most in terms of food stability (Devaux et al. 2021). Political stability, local economy, and price are all common elements that have the potential to affect food stability. Another factor that must be

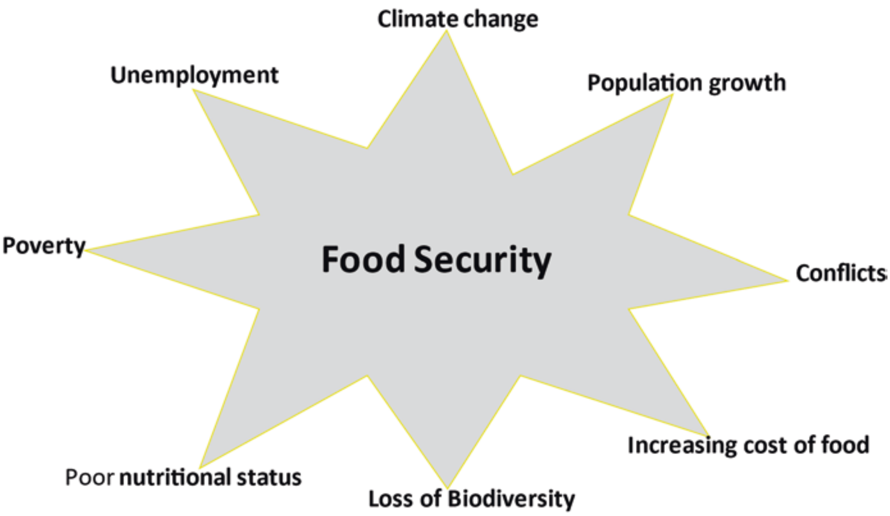

Fig. 3 Climate change and global food security issues

ignored are weather patterns that negatively impact agricultural production. It is widely accepted that a country, consumer, or household's vulnerability to external factors increases as its situation worsens (FAO 2015).

As was already said, the UN projects a 0.96% yearly enhancement in the number of people today and up to 2030, subsequently a 0.63% annual increase until 2050, leading to an increase in the total number of people on Earth from 7.3 billion (UNFPA) to 9 billion in that year. This population expansion is predicted to occur, particularly in low-income emerging nations, which historically have more severe challenges with food security than wealthy ones. More than 65% of the earth's population is anticipated to live in the cities by 2050. Urbanization is a global trend that will mostly impact low-income countries and will be a major factor in the creation of concentrated demand areas around the world, placing further strain on food supply networks. To fulfil the challenges of a growing population and increasing wages, worldwide agricultural and food product production will need to expand by 50% by 2030 and 110% by 2050, that is, between 2015 and 2050, higher-income nations are expected to have a 40% rise in meat demand $^{1-}$kg $^{1-}$person $^{1-}$year, whereas lower-income countries would see a 69% increase. Similar to this, it is expected that between 2000 and 2050, the need for dairy goods will shoot by up to 70% (Maggio et al. 2017). Between 1961 and 2011, the global food output increased by 122 million metric tons annually on average (Dou et al. 2016).

Degraded soil, lack of management of water, and urbanization are a combination that has led to ecological reserves, which are major causes of the land's unsuitability for agriculture. As a result, we must not overlook further essential natural resources, for example, consumption of energy and reliance on fuel, that, if not adequately managed and monitored, directly threaten global food security. When possible, we should try to employ renewable energy sources to reduce our carbon footprint. Recent statistics state that people utilize approximately more than half of the vegetated land of planet for the production of food (WRI 2013). Similar to this, it is assessed that ten million hectares (ha) of cultivable land is lost each year due to soil erosion, with an extra ten million hectares lost because of irrigation issues (Maggio et al. 2017). Seventy percent of the fresh water used in agriculture and food production is currently overused and not seen as a valuable resource. According to the NRDC, in actuality, 104 min of household shower use uses the same amount of water as one pound of chicken. Similarly, white rice, meat, tomatoes, and bananas, which each weigh 1 pound (0.45 kg), require 5, 42, 60, and 370 min of running water from a household faucet, respectively (NRDC 2016). It is well known that regional climate variances are used to encourage the production of a wide range of goods. The regional economy and productivity are significantly impacted by climate change and weather events, which can cause population shifts and resource depletion. Inconsistencies in resource delivery channels to market have a severe negative influence on both supply and demand for food globally.

Investors are worried that due to economic pressures, food supply systems that have historically been used for the making of food may now be used for generating biofuels. Sugarcane, maize, and oilseeds are examples of conventional crops that have been repurposed for the production of biofuels. This might considerably reduce consumer's reach to locally manufactured goods and prevent locals from purchasing meals, both of which would be detrimental. The entire supply chain is impacted by the infrastructural issue, as are all participants. While certain foods are grown in normal agricultural settings and are subject to seasonal weather conditions, other foods are produced in manufactured (artificial) environments and demand a huge level of monitoring and control. In order to boost production and, in many situations, reach the requisite size, more industrialized countries can systematize and improve the system or the environs at the secondary processing stage. Once again, many countries rely on human labor because they lack highly automated industrial techniques (Tenenbaum 2008). Consumer goods are frequently offered in beautifully packaged and personalized packets with marketing and nutritional information in more developed countries, which also extends the shelf life of the food. This is frequently not the case in less developed nations, where products are frequently at the mercy of the immediate environment in which they are carried and housed. According to some estimates, developing nations could save 200 million tons of CO_2 (14% of global consumption) if they utilized the same amount of refrigeration as developed ones (Mc Carthy et al. 2018).

7 Conclusion

Because it affects agriculture and the products it produces, climate change is a problem for everyone on the planet. Industrialization and hazardous gases are the main contributors to global warming, which eventually disturbs the planet's ecosystem. Climatic changes are wreaking havoc on the earth's development and output. Abiotic stressors are the most common form of stress experienced by plants. To better understand how plants respond to varied abiotic conditions, it is urgently necessary to look into the genetic basis of these systems. Some physiological and molecular problems in plants must be addressed to improve plant adaptability under abiotic stresses. Swings in temperature and modifications to precipitation patterns are significant indicators of environmental stress. Both good and terrible outcomes can result from changes in the weather, but the unpleasant outcomes are more mentally taxing. Overcoming the agricultural imbalance brought on by climate change is incredibly difficult. How to tackle this subject and what methods to employ are still up for debate. Therefore, in the face of abiotic difficulties, researchers must focus on maximizing plant development and growth. Future agricultural preservation may need the adoption of new and smart cultural practices, a variety of cropping plans, and a range of conventional and unconventional strategies. Climate-resilient crops that are more resistant to drought and heat should be developed as a result of breeding procedures, genomic selection (GS), genome-wide association studies (GWAS), high-throughput phenotyping, and genotyping methods; all contribute to the discovery of new and different types of genes that can serve for the improvements of crops under changing climate. Transgenic plants that are more resistant to a range of biotic and abiotic stress responses have been developed using genetic engineering techniques. To combat climate change, we'll need to develop environmentally friendly genome-modified crops using CRISPR/Cas9-mediated genome editing.

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Engineering Principles of Precision Farming: Pathway for the Developing Countries to Ensure Food Security

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Abstract Precision agriculture is the precise application of the inputs through the use of modern tools and technology to optimize crop production while maintaining soil fertility. Development in precision agriculture is required as environmental sustainability is considered to ensure the food security of the swiftly growing population globally in general, and for the people of developing countries in particular who are mostly at risk of food insecurity. The use of variable rate input through the variable rate technology for crop input such as seeds, lime, fertilizer, and pesticides is an effective management strategy to address the field variability. The reactive approach of precision agriculture requires the updated and latest technology of electrical and mechanical systems for the formation of variable rate technology. The two approaches of precision agriculture based on the predicted approach or reactive approach have different issues and levels of complexity. Both approaches have benefits and limitations in the application, and both will be used in the future for effective management. In this era, most of the technologies are commercially available, but their effective utilization and implementation require the capacity building of the farming community. The effectiveness of the adoption of the variable ate technology will not provide equal benefits to the farming community, but it will reduce the environmental hazards resulting from unrestricted use of agricultural inputs. The adoption of precision agriculture through the variable rate technology will not provide equal economic benefits, but it will provide the route path to select suitable technologies for better crop production while maintaining system sustainability.

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_7

The use of GPS, GIS, and remote sensing has provided the opportunity to map the field variability and factors affecting the optimum crop production, especially in the era of climate change. The sensors and ICT application improve the measurement and evaluation of field variability, and decisions are made for the improvement of crop production. The introduction of Agricultural Robotics and Unmanned Arial Vehicles increases the ease of adoption of precision agriculture technologies at a high resolution. The drone technology reduces the labor effort from the field evaluation to input application and mapping for the delineation of the management zones.

Keywords Precision farming · Developing countries · Food security · Climate change

1 Basics of Precision Farming

Precision farming is one of the ten new and latest methods in modern agriculture practices (Crookston 2006). It is often described as the application of the right amount at the right time in the right place. Accordingly, precision farming on the global scale was been applied to millions of hectares of agricultural land since the 1980s. The major focus is on the following aspects of precision farming: history and current status of precision farming in developed and developing countries; new developments for precise land preparation, precision sowing machinery, and its working principle; variable rate technologies for fertilizer and spray application; the application of geographic information system and its types and application in farming; the use of geo-positioning system and differential global positioning system; soil sampling and interpolation techniques using satellite systems, soil spatial variability analysis, basics, and application of sensing technologies; various types of proximal sensors used in farming for plant nutrients; soil spatial variability mapping and management; crop yield monitoring techniques; map-controlled application; information and communication technologies; internet information access; computer software for management and precision farming; introduction to agricultural robotics; and unmanned aerial vehicles. The aforementioned techniques are applied for the improved crop production while maintaining soil health and environmental sustainability. The use of information technology is extended into the agriculture sector to fine-tune crop inputs in order to improve production and profitability. In its simplest form, the basic of precision agriculture includes the use of sensing technologies and tools for analyzing the variabilities to implement the sustainable decision for improved crop production.

2 The History and Current Status of Precision Farming

From a historic perspective, it is interesting to note that major changes in agricultural technology have been met with ridicule and controversy. The conversion of farm power from horsepower to tractors was difficult in many areas of the world.

Milk transportation in the plastic canes was the practice from the dairy farm and continued in the developing countries. Shifting from the cane system to the chiller-based system was still a challenge for many people as it was thought to compromise the quality of the milk. Similarly, the revolution in corn production through the introduction of hybrid seeds was considered as being against nature. Similarly, in precision agriculture, the world is still facing the issue of major technological changes. The basic concept of agricultural accuracy, data collection, and decision-making based on that data has been around for many years. This was easy to do without any technology in small sections; as the size of the farm increases, however, this was no longer possible. Large farms need new techniques and tools for improved crop production under optimum resource utilization. The geographic information system (GIS) was probably the very first precision farming tool adopted in precision agriculture practices. In the 1960s and 1970s, GIS was only used by the researcher, and its commercial use was not very well established, especially among the farming community. GIS is a very sophisticated precision farming tool, but its adaptability was not very recognized at the time. Other devices were also developed from the 1980s to 1990s, such as yield monitors and nitrogen-testing sensors. The most important component of all of these was the global positioning system (GPS) integration for the site-specific management based on the location determined by the GPS receivers. The sensor technology is improved for the assessment of the soil's physiochemical condition at the real time. The innovation in the sensing technology triggers the evaluation of the field variability for the purpose of assessing the better crop production to ensure the food security.

Agricultural growth was accelerated dramatically in the last 100 years. This has been a combination of improved practices and the introduction of different technologies. Under these developments, farming shifted from subsistence to the commercial level. These changes in growth were due to the introduction of the new techniques and technologies that transformed the agriculture industry into a profit-driven one rather than one grounded in subsistence. Still, there is a desperate need to adopt the innovation and emerging technologies in agriculture to ensure the food security of the swiftly growing population. Farmers need sound judgment of the variability, and that is the key step before the adoption of technologies to increase yields while reducing the input costs. This type of decision poses significant challenges to the farming community for improved crop production. For example, in addition to the practical information available about the need for water or plant nutrients, farmers often spent more than the required amount. In addition, farmers had to put up with the labor-intensive testing of crops for hundreds of hectares to avoid any problems. Features such as these have enabled technology companies to meet their needs by providing the technologies to the farmers for better decision-making based on the fine resolution information collected through these technologies. This is considered the service-based precision farming concept.

Precision agriculture is the site-specific crop management practice based on the optimization of the water, fertilizer, and pesticide application in a controlled manner in order to reduce wastage and sustain the environment. The key purpose of precision farming is to equip farmers with the latest technology to improve production and profitability by applying the right amount at the right time in the right places.

Precision farming is one of the major pillars of the green revolution. The global increase in crop production was found in the 1930s and late 1960s due to technology transfer and its increased adoption in agriculture practices. The core objectives were to transfer the latest technology for better crop production. One of the important technology transfers in the field of agriculture was the introduction of GIS in the management of sources. In addition to these improvements, the green revolution also brought about the efficient utilization of the chemical fertilizer, effective water management practices, and high-yield variety utilization.

3 Precision Agriculture Scope

The agriculture industry is one of the world's major industries. In many countries, GDP's highest contribution is through agriculture production. In some countries such as Pakistan, agriculture can be seen in low-lying farm production, and there is misuse of crop inputs. The agriculture system is divided into two main categories in the majority of the developing countries: small landholding farming and large corporate farming. The agriculture sector in the developing world is facing the stress of low-yield production from these small farmholding communities due to the unavailability and less adaptability of the engineering technologies in crop production. The list of the major problems in this sector includes reduced yields, the increase in input prices, power shortages, water shortages, and the reduced acceptance of agricultural products in international markets. In addition, the lack of subsidies on agriculture requirements, the lack of availability of agricultural inputs, the shortage of information from social media, negative agricultural policies of the government, lower returns, and the decreased availability of irrigation water were having a negative effect on the agricultural community and farmers.

The established practices in the farm management in the majority of the developing countries are based on the general recommendation of the inputs for the whole field. Field sizes may vary from one acre to less than ten acres under this decision. This increases the initial costs due to the inefficient application of chemicals and increasing trends in the environmental issues, in particular the degradation in the quality of groundwater. Before the evolution of agricultural machinery in the world, farmers used a variety of pesticides to make small plots of land. Now advances in the agriculture machinery provided large-scale operations timely and efficiently. Similarly, a significant increase in the use of machinery in the developing countries used for the development of the agricultural lands, but it was very difficult to consider the geophysical variation without the development of technological change. The assessment of the variation was not considered initially with the advancement in the farm's operational machinery. Now the recent advancement is continued in the assessment of variation while performing other operations in the fields. The technology-driven implements and tractors are launched for the assessment of the field variability while performing the different field operations.

Precision agriculture works on the application of technology to implement the decision made based on the collected information. This is aimed at the use of technology as well as the principles of identification, analysis, and control of spatial and temporal variability corresponding to the production from farms to achieve the maximum benefits, ensure sustainability, and improve plant performance under the protective measures of the resources and environment. It is well established that agricultural accuracy is a multifaceted method that covers the scope of many topics, such as the diversity of soil resources, soil cultivation, irrigation, crop rotation, mechanical operation, plant genetics, and biophysical and chemical inputs. Precision agriculture is the key concept that determines the engineering-based solutions for crop cultivation, the estimation of irrigation water demand, and the design of the sustainable machinery for the site-specific management. In short, the aim of precision agriculture is to design and develop the agricultural resource optimization technologies for improved crop production in a sustainable environment.

The acceptance of precision agriculture is now perceived as a positive change in the developed countries, especially in Europe, Australia, and the United States, even though the adoption in these countries is slow. The adoption of precision agriculture in the aforementioned countries shows that the application of the inputs has been reduced without any decline in the crop yield. The significant adoption of precision agriculture is only possible if the law implementations and agriculture departments of the local governments spread the knowledge of fewer resource utilization and improved farms. The adoption of the new technology in precision agriculture improved crop production in the developed countries and created the challenge for the developing countries to enhance their crop production by adopting the precision technologies to ensure food security. This challenge is widely accepted by different developing countries to ensure optimum crop production. The list of those countries that have now adopted the precision agriculture includes Argentina, Brazil, China, India, and Malaysia (Tiwari and Jaga 2012; Shahid et al. 2014; Shakeel et al. 2014; Amin et al. 2015).

In developing countries, precision agriculture technology is in the developing phase through the indigenization of the agriculture machinery to make it more cost-effective. For example, in the case of Pakistan, technology development started around two decades ago. Before the start of this development, in the region of Indo-Pak, the major farm power sources were human and animals. Later, the introduction of technology such as tractorization became increasingly popular in this region, but the adoption of modern technology is still comparatively rare. The term tractorization defines the adoptability of the tractor at the form with limited improvements. The farming community was practicing only the cultivator as the main tillage tool for all crops as they were shifted from the single tine cultivator driven by the oxen or bulls. The use of the tine cultivator was the main adopted implement since its introduction in many developing countries. None of these implements were able to cater to field variability in order to improve the crop productivity. These existing practices are based on the general recommendations, from cultivation practices to the application of fertilizer, pesticides, and irrigation. The use of modern technology in precision agriculture provides the fine resolution assessment of the field variability of the site-specific crop management. The small landholding of the farming community requires the initial management of the fields to ensure higher crop production. This is a necessary improvement for precision agriculture in order to yield the maximum benefits. The adoption of precision agriculture technology can make a big difference, even in the area of small landholding. This type of farming can be easily managed even for the multicropping pattern. The improved technologies will only provide the targeted inputs more easily to each crop under the multicropping system. The intercropping is a recent advancement to improve the crop production with minimum field practices. The application of the precision technologies will boost its impact with sustainability.

4 Development of Precision Agriculture

The development of precision agriculture began in the early 1990s when Pierre Robert organized the very first meeting on "Soil Specific Crop Management." Robert had completed his PhD in 1982 under the supervision of Richard Rust in the Department of Earth Sciences, University of Minnesota. His dissertation was entitled "Examination of Some Specific Approaches to soil Management and Plant Management." In Robert's book, he continuously stressed that dissimilar patterns in the fields were the result of variations in the soil. He noted that "An important contribution of remote sensing in soil and crop management is not as a real-time tool but as an inclusion in the data management system of plant management." Carr et al. (1991) conducted experiments on the comparison of the soil-based fertilizer management in Montana and North Dakota. They found that there was no significant difference in uniform economic returns compared to the Montana-based soil management strategy. In North Dakota, the best economic strategy for planting rain-fed barley and wheat was either the use of the same nitrogen fertilizer based on composite soil samples or a flexible N strategy involving combining soil samples and yield terms by making a soil map unit. Flexible fertilizer application rates based on a sample space of a 15.2–30.4 m grid have generally been able to increase crop yields compared to similar techniques but it is found that they also incur additional costs that make these strategies ineffective.

5 Information Flow of Precision Agriculture

Precision farming has the potential for the efficient utilization of natural resources to maintain sustainability. According to the literature, there are a well-defined four definite stages for the implementation of precision agriculture: (a) defining the scale and extent of the soil variability and crop characteristics, (b) describing the causes

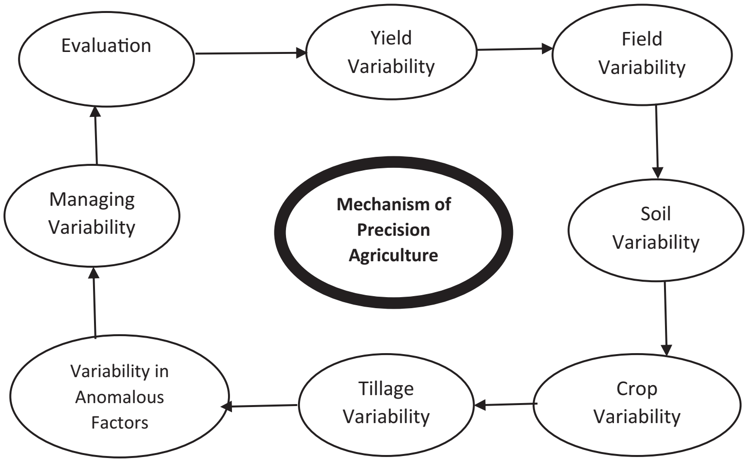

Fig. 1 Mechanism of precision agriculture

of the variability, (c) management of the variability on the defined scale and extent, and (d) evaluation of the variability management on the production and sustainability of the resources (Shanwad et al. 2004; Zaffar et al. 2014; Naz et al. 2013; Masood et al. 2013; Saeed et al. 2013; Sultana et al. 2013; Nasim et al. 2012a, b, c, d, e). The basic categories in precision farming include precise assessment of soil variability and plant characteristics and spatial and temporal variability management. In the following lines, the mechanism of precision agriculture (Fig. 1) is discussed.

5.1 Variability Characterizations

- Yield variability: Assessment of the yield variability in the fields.
- Field variability: Assessment of the field variability.
- Soil variability: Assessment of the soil's physiochemical variability.
- Crop variability: Assessment of the crop variability at different spatial and temporal scales.
- Tillage variability: Assessment of the tillage variability.
- Variability in anomalous factors: Variability in the other factors that affect crop production.
- Managing variability: Management of all the aforementioned variability.
- Evaluation: Evaluation of the decision made under the managing variability based on the assessment of the aforementioned factors affecting crop production.

6 Current Practices in Precision Agriculture

Water is the basic resource for agriculture on earth and it requires appropriate and sustainable management strategies. In this regard, precision agriculture plays its role in its efficient use to ensure sustainable agriculture production, even in the water-scarce countries. The demand for good-quality water is increasing as the irrigation sector is facing acute water shortages due to increasing water demands in other sectors and the impact of climate change. Irrigated agriculture is the major consumer of irrigation sources with low efficiency, and improved practices of irrigation are essential to improving the efficiency of water use. Therefore, significant progress has been made in improving water use efficiency in the recent past, and it has been the main focus of many researchers as agriculture is the largest user of available water resources. The concept of real-time control and efficiency of irrigation is in the development stages, but has already shown the potential to save water. The future may see an increase in the use of remote control sensory techniques, wireless communication systems, and flexible sensors in order to improve the efficiency of water use. In many cases, water conservation has been promoted through the use of effective technology for recycling the water for irrigation and eventually increasing the land area under irrigation. Therefore, to achieve water conservation, technology that saves and produces water should be used in conjunction with other methods. Such technology must be used to regulate the distribution of water for the reduction of the losses at different stages of distribution. Factors that affect water use efficiency include engineering and technological innovations, industrial development, environmental factors, and social and economic considerations.

Irrigation is an important agricultural activity which produces food, fodder, and fiber in the soil. In many countries, including Australia, water use and management are of great concern. Most irrigation water is available from rivers and dams and is conveyed by using open channels or pipes to irrigate farms for storage before use or direct application to the root zone. Irrigators who use groundwater often have storage tanks in their areas. At the farm level, commonly used methods of irrigation can be broadly classified as basin irrigation, border irrigation, furrow irrigation, sprinkler irrigation, and drip irrigation systems. Basin, border, and furrow irrigation are older surface-based irrigation methods. In most countries, surface irrigation through the network of the canal system is the most common way to irrigate row crops. In sprinkler systems, irrigation is applied in the form of artificial raindrops through a high-pressure nozzle system. In drip or trickle systems, water is delivered through the network of the pipe system with the help of emitters installed on the laterals, either above or below the ground surface. Drip irrigation, by contrast, is the gradual application of irrigation water available on or under the soil according to the final volume or the absorption rate of a particular soil for use in crop production. A device that drains water from the network of pipe systems under the pressure is called an “emitter” and may be pointed sideways or that may be built on a sideline. The size, width, and shape of the emitter affect the operating pressure in the discharge area, and a small amount of water is released. Flowing water from the discharge areas enters the ground and progresses with capillarity and gravity. Sprinkler systems and drip/trickle are also called pressurized irrigation systems, as they operate under high pressure, which usually involves the use of a pumping unit.

Globally, it has been estimated that about 70% of the world's fresh water is used to irrigate 25% of the land globally and provides 45% of the world's food (Thenkabail et al. 2011; Sajjad et al. 2012; Nasim et al. 2011, 2012b). Water for industrial and domestic purposes accounts for between 10% and 20% of all water used worldwide, respectively. Demand for freshwater resources is growing, and this trend is likely to continue to increase with the increasing demand for food and fiber, as well as the negative effects of climate change. It has also led to an increased awareness of the requirement to provide an adequate water supply for the provision of other natural resources. Therefore, this requires increased efficiency in the use of scarce water resources, a concept technically called efficient water use.

6.1 Irrigation Methods and Systems

6.1.1 Surface Irrigation Methods

Surface irrigation is the widely used method to irrigate agricultural lands globally due to easy flow handling, little expertise requirement, lesser management, and no power requirements. Different surface irrigation methods are used, including border, ridge, furrow, bed, furrow, and basin. The adaptability of the relevant method depends largely on the farm size, the availability of machinery, soil type, and targeted crop for production. Water saving varies for different crops, ranging from 30% to 50% depending on the aforementioned factors. Moreover, some innovations such as the mulching of plastic film on beds and surge irrigation have been introduced to further improve the efficiency of surface irrigation. However, surface irrigation methods are assumed to be the least efficient. The innovation of technologies such as laser land leveling and laser grading has significantly improved the water application at the farm level and also increased crop productivity. Both technologies ensure a rapid advance time and an almost similar infiltration pattern, depending on the soil type. However, the laser grading is more suitable for better irrigation efficiency in different soils. The research shows the significant potential of precision surface irrigation in the Indus Basin Irrigation System (Anwar et al. 2016; Chaudhary et al. 2011; Hammad et al. 2010b; Wajid et al. 2010; Usman et al. 2010). The conjunctive water use is also found suitable under precision surface irrigation (Anwar and Ahmad 2020). The working principles of the laser grading is presented in Fig. 2.

6.1.2 Drip Irrigation

The drip irrigation method is very efficient because it reduces conveyance losses and directly provides water to plants. This increases the yield per unit of water, thereby increasing water use efficiency. Irrigation with a drip system also increases the efficiency of fertilizer application and, as a result, reduces the total production

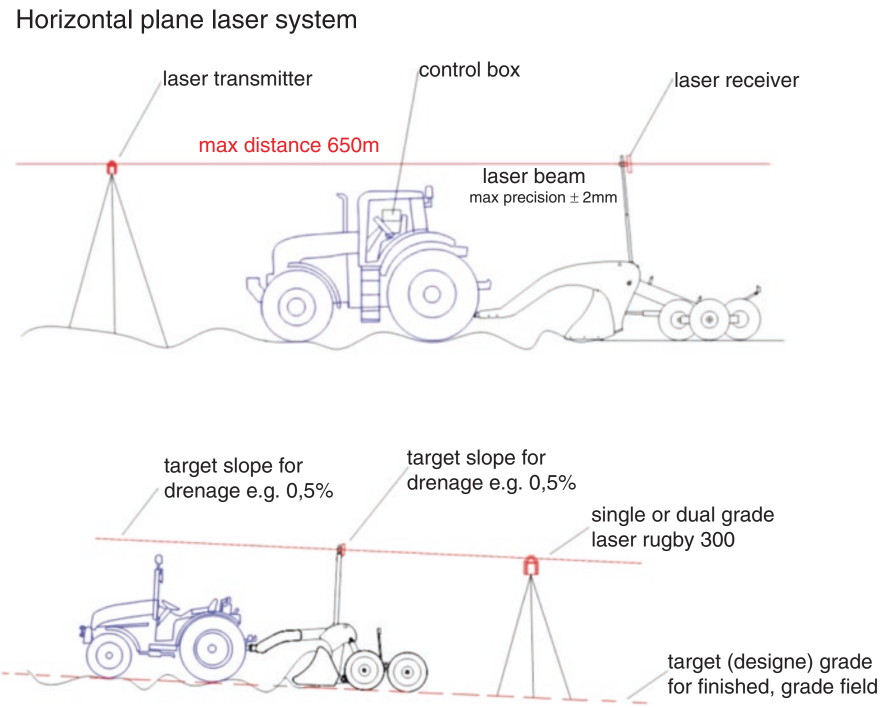

Fig. 2 Laser land leveling and laser grading principles

costs. The performance of drip irrigation is not affected by wind speed. Moreover, weeds are less likely to grow in parts of the field that is not irrigated, thereby reducing weed impact on crop production. Ensure uniform crop growth and very high-quality produce due ti timely fertigation. Controlled and frequent irrigation to crop ensures timely crop maturity by keeping the root zone aerated throughout the irrigation period. Daily watering keeps the soil moist and soft, so the roots of plants can easily penetrate. This method is effective for hilly and sloping areas where topography does not allow the surface irrigation systems. Therefore, there is a gained significant adaptability in the hilly areas, especially in the Potohar region of Pakistan. Figure 3 shows the drip irrigation system installed in an orchard.

6.1.3 Drip Irrigation Limitations

The drip irrigation system is a highly expensive irrigation system in terms of its initial installation cost. The drip irrigation system requires a source of energy to operate and thus increases the production costs. The successful use of drip irrigation systems requires continuous monitoring and maintenance, which is difficult for the common farmer. If the saline water is used continuously for irrigation, then it affects

Fig. 3 Drip irrigation system installed in an orchard

the soil and demands additional irrigation supplies for the leaching of salts from the root zone. Moreover, salt accumulation can also shock the emitters and create problems with the filter system.

6.2 Sprinkler Irrigation System

In this irrigation system, water is applied to crops through a series of sprinklers which ensure the equal distribution of the water in the field. The irrigation efficiency is reported as being up to 85% and saves 10–16% of the land by removing channels that are otherwise needed in surface irrigation supplies. These sprinklers are connected through the pipelines. The pressure in the system is produced by the pumping unit. By the careful selection of pipe sizes, operating pressure, and spraying spaces, the amount of irrigation water is needed to refill the root zone of the crops by applying the irrigation at a rate less than or equal to the soil infiltration rate. The system can be used effectively in small to large cultivated areas, especially for sandy soils. However, this is not recommended for very fine soils with an infiltration rate of less than 4 mm/h. The sprinkler irrigation system is very suitable for those areas with higher slopes or unusual topography. If soil is vulnerable to erosion, sprinkler irrigation can be used in conjunction with contouring, terracing, mulching, and strip cutting. Fertilizer and pesticide applications can be done economically with the irrigation water by adding small equipment, and the system saves the extra work, time, and cost needed to apply the fertilizers, pesticides, and herbicides. Sprinkler irrigation can be used to protect crops from frost and low temperatures that affect the yield and quality of the crop.

Fig. 4 Sprinkler irrigation system

This system allows efficient use of small available water supplies to irrigate shallow soil and provides better control of the installation of water that is suitable for providing light and frequent irrigation and efficiency of the water application close to 85%; it is suitable for vegetable and cereal crops. The system allows the partial or full coverage of the fields, and the chances of the sprinkler system nozzles becoming clogged are less than compared with the drip irrigation system. Figure 4 present the installed sprinkler irrigation system.

6.3 Types of Sprinkler Irrigation Systems

Based on sprinkler heads and the portability of systems, sprinkler irrigation systems are classified into several types. The most common types of irrigation systems are described below:

6.3.1 Rotating Head Systems

The rotating head sprinkler system consists of the small size nozzles mounted on the riser which are equally spaced and installed on the lateral pipes of the sprinkler system. In this system, the lateral is placed on the ground surface, while the mainlines are buried in the ground below the cultivation depth. The pumping unit is connected to the mainline to provide the sufficient operating pressure. The system is also mounted above the crop high to provide the sufficient irrigation in the targeted areas in a rectangular pattern as the degree of rotation is at 90°. In this system, spray heads are rotated due to the impact of water and are generally known as impact-type sprinklers.

6.3.2 Perforated Pipe Systems

The perforated pipe sprinkler system consists of the equally spaced nozzles along the length of the pipes from irrigation that is done under the operating pressure. These system works for the small-scale irrigation as the operating pressure varies from 0.5 to 2.5 kg/cm^2. This level of operating pressure can be achieved by connecting the pipe with the overhead tank. As the nozzles are made on both sides of the pipes, the average area covered mostly falls between 6 and 15 m. The area coverage also depends upon the scale of the operating pressure. The suitable site for this system is considered with the high infiltration soil as the system provides high flow rates. These types of sprinkler systems are considered more suitable for irrigating plants whose height does not exceed 40–60 cm, such as grass, gardens, and small vegetable gardens like the concept of kitchen gardening.

6.3.3 Portable Sprinkler System

These systems use a back pipe with periodic fittings. The side pipe is usually made of aluminum with various lengths of sections, that is, 20, 30, or 40 ft, and has a special connection that connects quickly to each pipe area. The sprinkler is fitted with a single pipe riser to operate above the cultivated plant. The risers are connected to the side where the pipes meet, and the length of the pipe section is selected to match the desired spraying space. The lateral pipe of the system is placed on the same site till the completion of the irrigation to the selected field, and then these lateral are moved to the next position for the irrigation to the next field or the desired field. This type of sprinkler system has low initial costs, but with high labor requirements. It can be used in many crops, such as corn, and the side parts are difficult to move as the crop reaches maturity.

The solid-set sprinkler irrigation system is the most expensive sprinkler system in terms of its capital cost and it is the cheapest in terms of the operating cost. In this sprinkler system, the lateral are placed in fields at the time of sowing and removed before the harvesting. The irrigation flow is regulated through the value system to provide the sufficient discharge at the time of requirement. This system requires extensive labor at the time of installation and at the time of removing the system from the field. In this system, the main pipes are buried under the surface below the depth of cultivation. These types of systems are expensive but operate under the automated system to retain the moisture in the roots according to the requirement.

Fig. 5 Rain gun irrigation system

6.3.4 Rain Gun Systems

The rain gun irrigation system is a specially designed sprinkler irrigation system for the high flow rate and vast area coverage through the high pressure thrust. The working pressure is relatively high among the other designed sprinkler systems with the range of 2–7.5 kg/cm^2. The flow rate of the rain gun system varies from 3 to 30 l/s and the operating nozzle diameter is about 10–30 mm. The area coverage of the rain gun having the aforementioned specification varies from 27 to 60 m. The rain gun system is very efficient with the equally distributed pressure and uniformity of the water distribution at the whole coverage area. The variation in the radius of coverage and flow rate can be adjusted as per requirement. The trajectory path is easily adjustable to control the angle of application and mitigate the wide effect. The rain gun system is highly recommended for the large coverage field crops which include sugarcane, oilseed crops, pulses, tea, and coffee. Figure 5 shows the working of a rain gun in a maize field.

6.3.5 Central Pivot Systems

The central pivot sprinkler irrigation system is made of counted towers in series, upon which nozzles are mounted. The ending part of the connected towers has the nozzles that also covered the corner areas. One part is connected to the pumping unit, which is also the point of rotation. The time to complete one rotation ranges between one hour and several hours. The performance of the system depends upon the flow rate from the mounted nozzles, the operating pressure from the pumping system, the speed of the rotation, the irrigation water requirement, and the type of soil. Center pivots can irrigate many field plants, but they are sometimes used on

Fig. 6 Central pivot irrigation system

trees and vineyards. Linear motion systems are similar to the center pivot systems, with the exception that there is no fixed pipe end. Figure 6 shows the central pivot irrigation system on a large field.

6.3.6 Sprinkler System Limits

The major limitation of sprinkler irrigation systems is their high initial costs and operational expenses due to the requirement of excessive use of power to create working pressure from 3 to 6 bars. Moreover, the requirement of skilled labor for operating the system requires additional costs. The areas having high winds disrupt the equal distribution of water, resulting in uneven irrigation. This uneven irrigation causes the over-irrigation and under-irrigation at some parts of the field. The continuous direct irrigation may cause some fungal disease, leave burning, and damage to fruits due to the accumulation of salts on the leaves. Extensive labor is required to move the sprinkler on large area. A portable system becomes blocked in the case of long trees or plants in the fields. The proper maintenance and care is compulsory to run the system for a longer period and in order to justify the cost. System failure occurs as a result of improper maintenance or the unavailability of skilled labor or a technical operator.

6.3.7 Laser Land Leveling

Traditionally, farmers often used to level the soil in their fields using tractor-drawn plows called scrapers. These are simple implements that comprise a hook and a small bucket to turn the soil from a high point to a low point. Traditionally balanced or unequal soils lead to low levels of irrigation efficiency. A large amount (10–25%) of irrigation water is lost during farm irrigation due to poor management and unequal fields. Over-irrigation in low-lying areas removes soluble nutrients in the root zone of plants and makes the soil less productive. On the other hand, plants receive stress at higher levels, causing growth to be negatively affected. Technological options for advanced production and profit are expected to improve the efficiency of water use and, consequently, increase production. Precision land leveling helps control the beginning of soil salinity, thereby increasing crop production by 3–5%, improving crop development, reducing weed growth, and saving water for irrigation. Laser leveling is a process of smoothing the soil ±2 cm from its central height by using laser-assisted drag buckets to achieve precision ground measurement. Precision measuring the ground involves changing the fields in such a way that it creates a constant slope of 0–0.2%. This practice uses large horse tractors equipped with global positioning and/or laser-guided instruments to move the soil by cutting or filling to create the desired slope.

The laser leveler consists of (1) an emitter which emits a fast rotating beam and is placed on a tripod and (2) a receiver which is carried by a sensor mounted on a tractor near the scraper unit. The received signal then actuates the scrapper through a hydraulic system into cutting and filling level adjustment. The direction of the scraper is fully automated; user error features are removed, which allows for a fairly precise ground measurement. Figure 7 shows the laser land leveling at the research field of Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan.

6.3.8 Benefits and Limitations

The benefits of this system includes the laser-controlled soil accuracy, which helps to improve both plant growth and crop maturity. Laser land leveling increases water efficiency by up to 50%, controls the movement of salts into the soil, and saves

Fig. 7 Laser land levelling at Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan

irrigation water by about 35–45%. The limitation includes the high cost of laser implementation and the need for a skilled operator to set/adjust laser settings and operate the tractor. However, the government supports these services from its allied departments and, in some countries, provides subsidies to farmers for the purchase of these pieces of equipment.

7 Variable Rate Technologies

The variable rate technology began with the idea of fertilizer application at different rates on different parts of the field based on the requirements in the early to mid-1980s. Gradually, the variable rate technology has come to replace the concept of traditional farming. Similarly, the US university scientists started working on the concept of variable fertilizer application in the late 1980s. The concept of the variable rate of fertilizer application yielded both economic and environmental benefits. The selective application of fertilizers decreased the input cost, improved the efficiency of fertilizer use, and improved crop production. The variable rate application of fertilizer protected the soil and water quality due to the reduction of its application under traditional pattern of fertilizer application.

The use of variable rate input through the variable rate technology for crop input such as seeds, lime, fertilizer, and pesticides is an effective management strategy to address field variability. In the reactive approach of precision agriculture, the on-the-go requires the updated and latest technology of electrical and mechanical systems for the formation of variable rate technology. The two approaches of precision agriculture, based on the predicted approach or reactive approach, have different issues and complexity. Both approaches have benefits and limitations in terms of their application, and they will be used in future for effective management. In this era, most of the technologies are commercially available, but their effective utilization and implementation require the capacity building of the farming community. The effectiveness of the adoption of the variable rate technology will not provide equal benefits to the farming community, but it will reduce the environmental hazards produced due to unrestricted use of the agricultural inputs. The adoption of precision agriculture through variable rate technology will not provide equal economic benefits, but it will provide the route path to select the suitable technologies for better crop production while maintaining the system's sustainability.

8 GIS Application in Agriculture

The first geographical information system (GIS) was created by Canadians in the early 1960s to store geospatial data and create maps for the Canadian Land Inventory. This information revealed the global potential for agriculture, wildlife, forestry, and recreation. The GIS technology was not particularly familiar about a decade ago, but it is now the most important and widely accepted and utilized tool in the agriculture production system. GIS has become the most important tool for the site-specific crop management through the development of the management zones. These practices are valid for the reduction of the input cost and productivity enhancement. The application of the GIS for the improved crop production is developed based on the real-world information through the random collected data of the fields and the satellite information. The sensing technology used for data collection ranges from agriculture machinery-based sensors to satellite systems.

Precision GPS has become an important tool for workers in the agricultural industry. For farmers, technology provides numerous cost-effective and productive benefits, as well as social and environmental benefits. The use of mechanical sensors to collect information about plants and GPS to immediately record the area used in the field is an important example. The technology, therefore, allows fertilizer to be applied only where it is needed, and the application rate may be changed to target nutrient-free areas. This saves money on fertilizer production and protects the environment by preventing local rivers and streams from overflowing and flooding. Satellites and drone use have grown exponentially in the past few decades in precision agriculture. One of the core challenges in the agriculture system is the management of water resources. Water accounting is the main pillar involved in improving and enhancing water productivity. Remote sensing and GIS made it possible to assess water accounting at different spatial and temporal scales. The management factors for the improved crop production and water management include soil salinity, groundwater level and groundwater quality, surface water supply, rainfall pattern, soil moisture, flood, and drought. The spatial and temporal mapping of all these factors provides sufficient information for the making of better decisions regarding improved crop production.

Satellite-based information has the course resolution than the drone technology. Drone technology collects the very fine resolution information and performs better management operations. The fine resolution data collected through drone technology includes plant-based information such as plant height, plant biomass, the number of plants, weeds and other diseases, and the level of nutrients. The regular monitoring on the large fields is also performed through the drone technology. Drone technology helps the farmers to make real-time decisions. A single drone can empower farmers to make many powerful decisions which will affect the field's level of production.

The agricultural industry has undergone a major transformation with the introduction of geospatial technology. Over the past few years, the power of the Internet and GIS access and digital mapping have both changed the way in which farmers manage their land and perform their basic functions. GIS allows us to visualize, analyze, and comprehend the vast area of data that is stored and collected daily. It is now possible to give an easy explanation of which crops thrive, the level of pollution, and natural disasters that hinder the production and control of fertilizer use.

9 GPS and DGPS System Use

Site-specific crop management through the delineation of precisely developed zones is very important in precision farming based on the soil and crop yield variability. The distribution of the inputs based on the variability assessed in the farms and delineated zones is also very important for improved crop production. The delineated maps provide the georeference-based information to provide the required amount in the right place. Initially, it was a difficult task to identify within-the-field variability, but the use of accurate GPS made it very simple in the modern era. The GPS-mounted machinery performs these field-based operation very effectively. The connectivity of the four satellites made the accurate decision in the agricultural fields for the application of the crop inputs and other management practices. The approach of changing the real-time difference was chosen over the real-time kinematic position, which involves continuously calculating the phase of data from at least four satellites on both the primary and oriented receivers. When a roaming receiver passes behind a tree, building, or hill, there can be a loss of signal, leading to real-time kinematic failure. The primary motivation for GPS precision farming was to identify compound areas and collect real-time data on grain harvesting position fluctuations. Later, attention to GPS switched to its usage in the areas of agricultural equipment navigation and autosteering. This program comprises hardware, software, and image data, as well as information on geographical surveys, management, analysis, and demonstration. In a conventional integrated system, a GIS may receive, organize, quantitatively analyze, and display various types of digitally identified location data. When these databases are built and covered with fresh combinations in databases, allocation decisions can be made continuously. Figure 8 shows the differential global positing system available at KFUEIT, Rahim Yar Khan, Pakistan.

Fig. 8 Differential global positioning system, KFUEIT, Rahim Yar Khan, Pakistan

10 Geostatistics

The assessment for quantifying the soil variability within the agriculture fields was started during the 1970s and 1980s by the soil scientist. Initially, they started on the assessment of the variability of the soil moisture and soil hydraulic parameters. The use of geostatistics started with the core purpose of assessing the water and salute transport in the unsaturated zones. Similarly, the spatial mapping of soil was also understudied using the geostatistics approach. The application of variable rate fertilizer was not the aim of the soil mapping during this time.

Parallel research on the spatial variability of soil was also conducted. Mulla's research came to the attention of Max Hammond, a crop consultant working for CENEX Land O'Lakes and Soil Teq, and in 1986, Soil Teq, from Waconia, Minnesota, hired Mulla as a consultant to write software that automatically reclassified and mapped soil fertility sampling data into fertilizer recommendation zones, which Mulla called "management zones." The integration of the GIS and geostatistics started with this work of precision farming. The use of geostatistics in precision agriculture is extensively documented by Mulla (1988); Swinton & Lowenberg (2001); Hammad et al. (2010a); Oliver (2010)); Gebbers & Adamchuk (2010); Munis et al. (2012); Nasim & Bano (2012); Khaliq et al. (2012); Mubeen et al. (2013); Hammad et al. (2014).

11 Satellite Remote-Sensing Application

Agriculture, which is the engine of economic growth in many countries, provides essential human services such as nutrition and fiber. The sector has evolved dramatically as a result of technological advancements in the last century, such as the Green Revolution. The Green Revolution, or the so-called third agricultural revolution, enhanced crop output and food security, especially in poor countries, from the 1960s to the 1980s. It included advanced plant varieties, synthetic fertilizers, pesticides, and irrigation. As a result, despite a threefold increase in population density and a threefold increase in food demand since the 1960s, agriculture has been able to supply demand with only 30% of all producers located globally (Pingali 2012). By 2050, demand for food and agricultural goods is predicted to increase by more than 70%. Given the limited availability of agricultural land, a large part of this increasing demand will be met through agricultural intensification, that is, increased use of fertilizers, pesticides, water, and other inputs.

However, heavy use of agricultural inputs also causes environmental degradation, including the depletion of groundwater, reduced groundwater flow, and eutrophication. Excess and/or limited use of natural resources (e.g., soil and water), fertilizers, and pesticides in agriculture production causes economic losses and increases the loss of water and nutrients from agriculture leading to environmental degradation. To achieve an economic and environmental sustainability production system, there is a need to develop strategies that can increase crop production through the increased use of inputs and reduced environmental losses. Precision agriculture has been described in many different ways, yet the basic concept is still the same. Precision agriculture integrates a management strategy that uses a collection of advanced data, communications, and data analytical strategies in the decision-making process (e.g., water use, fertilizer, pesticide, seeds, fuel, labor), which help to improve crop production and reduce water and nutrient loss and adverse environmental impact. Information-based management, site-specific plant management, targeted farming, dynamic technology, and grid farming were all used similarly in precision agriculture. In addition to crop production, precision agriculture has been used to grow viticulture, farming, grazing, and livestock production and management.

Currently, agriculture can be considered as a transition to the fourth most important transformation through the development of information and communication technologies. Emerging technologies, such as remote sensing and GIS, GPS, Internet of Things, big data analysis, and artificial intelligence, are all promising tools used increasing agricultural efficiency and resources aimed at improving productivity and reducing inputs as well as yield loss. Many IoT technology applications use cloud computing, wireless sensor networks, and large-scale data analysis for intelligent farming activities such as automation telephone irrigation systems and intelligent diseases and pest monitoring and prognosis systems. Artificial intelligence techniques, including machine learning, have been in place used to measure evapotranspiration, soil moisture, and crop predictions for automatic use and water accuracy, fertilizer, herbicide, and pesticides. These technologies and tools enable farmers to highlight spatial fluctuations between farms and large plantations that harm crop growth and harvest. This is a modern technology for site-specific development, and implementation management is an important aspect of precision agriculture.

Remote-sensing systems, making use of information and communication technology, typically produce a large amount of spectral data due to the high resolution required in precision agriculture applications. Emerging data-processing techniques, such as big data analysis, practical wisdom, and machine learning, have been used to extract useful information from large amounts of data. In addition, cloud computing systems are used to store, process, and distribute/use such a large amount of application data in precision agriculture. All of this has improved data acquisition, and processing methods are used worldwide, to assist in the decision-making process of field crops, horticulture, viticulture, pasture, and livestock.

In the past, a few studies have provided reviews of remote hearing techniques and applications in agriculture. Land use and land cover development for the estimation of the cropped area assessment and water resource management component estimation at a high-resolution scale is an extensively adopted technique for effective management solutions (Awan et al. 2016; Cheema and Bastiaanssen 2010; Cheema et al. 2014; Cheema and Bastiaanssen 2012; Liaqat et al. 2015, 2016; Waqas et al. 2019). Although some studies have focused on specific areas that used evapotranspiration measurement, such as disease and pest control, others cover more than one application area. Many of these studies have demonstrated the artistic nature of distance-based strategies and their limitations and future challenges.

Remote-sensing systems for precision agriculture and agriculture, in general, can be divided into two categories: (i) sensory platform; and (ii) sensor type. Satellites, aerial, and terrestrial platforms are frequently coupled to sensors. Satellite goods have been regularly used in Pennsylvania since the 1970s. Aerial platforms, including airplanes and unmanned aerial vehicles, have recently been utilized in precision agriculture. In comparison to air-based or satellite platforms, supported systems are dubbed remote-sensing systems since they are placed close to the target location. Many plant indices and mathematical learning methods and equipment, including the neural network and random forest, have been employed to minimize the impact of hyperspectral data to extract significant information on plant conditions. Measurements of chlorophyll produced by sun fluorescence from hyperspectral images have recently been widely utilized to evaluate photosynthesis, plant genetics, and biotic and abiotic stress such as disease and water stress. Even though most modern satellites give high-altitude and transient corrections, most publicly available satellite products are reliable in most precision agriculture systems. The capacity of farm equipment to modify input application costs is dependent on various aspects, including management objectives, field size, and the ability of farm equipment to change input application prices. In comparison to variable fertilizer and irrigation level applications, crop yield and yield rate often require changeable height. Furthermore, weed map design and flexible herbicide administration necessitate a higher level of space fixation than weed sections. When compared to satellites, aerial platforms such as UAVs deliver high-resolution photos. So, UAVs, as well as other grounded platforms or greater flexibility in rendering images in a beautiful and temporary environment.

There are many ground-based remote-hearing stations with working sensors in the area. Applications like Green Seeker and Crop Circle, for example, feature active sensors near the amount of flexible fertilizer available for sale. That's true; in these systems, daylight variation has less of an effect on the light intensity, allowing for greater precision and viability of the plant index or other crop indicators used to measure plant nutritional condition. Two more sensors (thermal infrared and microwave) that have been placed in recent satellites are increasingly being employed in agriculture. Thermal infrared sensors detect energy emissions by detecting their temperature and can be used to continually monitor plant water pressure, evapotranspiration, and irrigation requirements. Microwave sensors, like heat sensors, balance power by emitting energy from the earth's surface. Microwave sensors are commonly employed in broad regions to assess soil moisture and plant water use. Microwaves can also penetrate clouds, which is an advantage over other types of sensors that use visible and near-infrared wavelengths.

However, microwave satellite sensors, particularly passive ones, require rough local adjustments. Sensors, on the other hand, are limited to precision agriculture. Microwave data for passive downscale for improved adjustment for use in precision agriculture has recently been created and applied in many ways. Active microwave sensors are frequently used for high-resolution localization; nevertheless, they are extremely sensitive to soil avoidance, which can cause soil moisture content

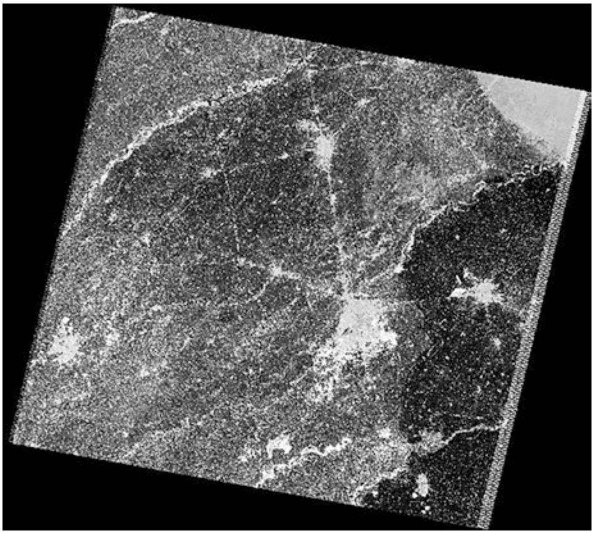

Fig. 9 NDVI from the LANDSAT Image

shortages. Overall, many remote sensors and platforms can be utilized to provide high-resolution images, which are necessary for developing and implementing site-specific management. In Fig. 9, the NDVI developed from LANDSAT 7 image is presented.

12 Sampling and Interpolation Techniques

Fertilizer use was recommended as early as the 1920s, but cheaper fertilizers and agricultural work prompted many farmers to move to uniform farming until the 1980s. Variability in soil fertility was significant, and sampling of a neglected part of the field could be an inaccurate approximation of general fertilizer requirements; later on, this created the theme of grid sampling. Fine grid sampling was carried out in the same area regularly till around 1994. However, until a few decades later, there was little practical implementation of this principle. Figure 10 represents the piezometers data in the Rechna Doab of Pakistan and Interpolation of the this data.

13 Yield Monitoring Techniques

The agricultural output varies geographically and temporally due to many limiting factors such as soil type, fertilizer supply, water availability, weather, and crop variety. It's difficult to evaluate the influence of these limiting limitations on crop yield, as well as the regional variance of crop output before harvest. During the season, the use of remotely sensed aerial images can aid improve estimates of agricultural production. However, the success of such methods is usually decided by the image categorization system utilized.

Fig. 10 Interpolation using GIS

14 Smart Sensors and IoT Applications

Farming efficiency hinges on a farmer's capacity to anticipate natural events and respond as promptly as possible. Due to quick data gathering and distribution, the precision of such projections was not as high a few decades ago as it is now. With increasingly complicated Farm Management Information Systems supporting everyday farmers' decisions, agricultural production management is entering a new era. The latter has evolved from simple record-keeping software to complex systems capable of manipulating large amounts of data and assisting with decision-making. Figure 11 presents the soil moisture sensor, developed under the Students Final Year Project at KFUEIT, Rahim Yar Khan.

15 Delineation of Management Zones

Local farming has a distinct mindset from land farming. According to soil farming, fertilizer requirements vary by soil type, but are similar within each soil type. Specific tillage suggested that there is a lot of variation across soil chain boundaries, and the only method to figure out how much fertilizer is required is to take grid samples or soil samples at the soil chain boundaries. The advantage of irrigated crops provided for a deep grid soil sample, which could be utilized to define the flexible P and K fertilizer control regions. The maximal grid space of the soil sample can

Fig. 11 Soil moisture sensor, Students Final Year Project KFUEIT, Rahim Yar Khan

be calculated using geostatistics. Soil parameters, including soil texture and organic matter content, are the most popular ways of classification of management areas, followed by sensitive approaches such as electrical conductivity maps and remote sensing. Crop map layout, followed by height variances throughout the field, are two other unusual ways of characterizing management areas. Similar practices are well applied for the detection of groundwater quality zones for irrigation purposes. The basic parameters of the groundwater irrigation quality are considered SAR, RSC, and EC. These interpolated maps are classified based on the irrigation water quality standard, and then management zones are formulated through the overlay approach in GIS. The figure represents the groundwater quality zones detected using GIS. Figure 12 shows the groundwater quality zones delineated using GIS.

16 Introduction to Agricultural Robotics and Unmanned Arial Vehicles

Over the past three decades, precision automated navigation has been one of the most active fields of research and application. This method has the advantages of decreasing user fatigue, eliminating mechanical strains, and increasing fuel efficiency. The mechanized cultivation of circular fields based on the distance to the

Fig. 12 Groundwater quality zones detected using GIS

center using a cable spool method automated the agricultural machinery. The use of radio balloons or microwave signals to automate agricultural machinery areas necessitated a clear line of sight and a significant set of equipment in the area.

GPS is the most prevalent form of precise autonomous navigation. The use of GPS for autonomous tractor steering in straight lines is becoming popular in agriculture practices. The tractor's steering unit is automatically guided by GPS, which is paving the way for speedier trade and implementation of autosteer technology in agriculture. GPS is utilized to drive the tractor over curved tracks, which is far more difficult than traveling in straight lines. Multiple sensors, such as GPS, geomagnetic directional sensors, and machine vision, are frequently used in recent efforts to improve navigation accuracy. Japan has been a pioneer in the use of all types of autosteering navigation technology, particularly in Hokkaido Island's tiny agricultural industries. Depending on the investment, automatic tractor rotation can take a variety of forms, including manual lightbar manipulation, and an assisted steering wheel, or autosteer.

17 Conclusion

Precision farming is an emerging field to ensure food security through the methodology of sustainable use of input resources. Precision farming is an art to implement the engineering principles to implement the management decision timely and correctly under a sustainable solution. This chapter provides the insight about the core engineering principles about the precision farming as a route path for the developing countries to ensure the food security while optimizing the resources.

Acknowledgments The authors acknowledged Mr. M. Ahmad Rustum (student of BS Agricultural Engineering) for the development of the images under the supervision of the Engr. Dr. Muhammad Mohsin Waqas, Assistant Professor, Department of Agricultural Engineering, KFUEIT, Rahim Yar Khan.

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GHG Management Implications for Developed and Developing Nations

Muhammad Farooq Azhar, Akash Jamil, Ehsan Ali, and Abida Aziz

Abstract Greenhouse gases are major triggers of climate change as trapping heat makes the planet warmer than the usual. A surge in greenhouse gas emissions has been most eminent in the current decade as compared to previous years. As in 2018 alone, global GHG emission was quantified to be at 55.6GtCo_2 eq. These emissions are variable and directly associated with the fluctuation in economy, fuel prices, and other factors. In developed and developing countries, gas emissions increased due to increased energy needs. The pollution emitted from these gasses is about 56% higher than 1990s. This upsurge can be controlled and even be reduced by innovating and investing in environment-friendly technologies and infrastructure. Innovation and management of GHGs can increase the effectiveness and availability of mitigation and adaptation options. Investing on technology and infrastructure usually depends upon permitting policy environment, access and availability to finance and enabling wider economic development. In different regions and various sectors in a community capacity to adapt and mitigate climate change, risks vary highly. These capacities usually differ depending upon a particular place and context. Thus, a single approach for risk reduction cannot be implemented across different regions. For example, developing countries having weaker economic, institutional, and technological capacities that make them limited in their approach toward pursuing climate-resilient and low GHG emission pathways. While on the other hand, communities in developed countries have enhanced capacity in managing the risks of climate change policy implementation. But this capacity does not necessarily mean that implementation of various policies is any easy.

Keywords GHG emission · GHG management · GHG mitigation · GHG policy implication · GHG control

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_8

1 Introduction and Background

Greenhouse gasses (GHGs) serve as a layer over the globe, capturing radiation and intensifying the temperature of the atmosphere. The GHG effect is an important phenomenon that helps to maintain temperature and make possible to live organisms on earth. The increase in GHGs emissions, on the other hand, can change World's atmosphere, putting human health and welfare, as well as ecosystems, at jeopardy.

1.1 Different Types of GHGs

Four main types of GHGs are frequently discussed in the scientific research studies and are specified in the Kyoto Protocol (UNFCCC 2008).

Carbon dioxide is a major greenhouse gas (GHG) in the atmosphere. Volcanoes, hot springs, and geysers are natural sources, and it is released from calcareous stones by the dissolution of water and acids. Groundwater, rivers and lakes, icecaps, glaciers, and oceans all contain carbon dioxide. Petroleum and natural gas reserves contain it.

Methane is a naturally occurring gas that is produced by geological and biological processes and may be found underground and beneath the seabed. Methane becomes atmospheric methane when it reaches the surface and enters the atmosphere (Khalil 1999).

Nitrous oxide is a significant ozone (O_3) scavenger with an impact equivalent to that of CFCs in the stratosphere (Ravishankara et al. 2009). It is the third most important long-lived greenhouse gas, which contributes greatly to global warming.

F-gases are man-made gases that can persist in the atmosphere for millennia, contributing to the global warming impact. The four types are HFCs, PFCs, SF_6, and NF_3. These different types of F-gases have a tendency to contribute in the global warming and climate change.

1.2 Status and Effects of GHGs in Developing and Developed Countries

The emission gap report of the UN Environment Program reported that in general GHG emissions in 2018 amounted as 55.3 GtCO2e. In 2018, globally, GHG emissions increased by 2% (UNEP 2019). CO2 emissions from fossil fuels and agricultural use contribute to approximately 74% of total world GHG emissions in 2018. The Intergovernmental Panel on Climate Change (IPCC) has predicted that human-caused global warming had increased by 1.0 °C over pre-industrial levels (UNEP 2019).

It is important to understand that how increase in GHG emissions effects on human and natural systems, as well as the threats and vulnerabilities they bring. Temperature, precipitation, extreme weather events, and ocean acidification were all emphasized in a latest study conducted by the UN Climatic Change Secretariat (UNCCS). Droughts, food shortages, heat waves, and landslides are just a few of the climate threats identified (UNCCS 2019). The Centre for Research on the Epidemiology of Disasters (CRED) reported that 315 natural calamities struck the world in 2018; the majority of them were caused due to increase in GHG emissions. Among the incidents, the cases were recorded 16, 26, 127, 13, 95, and 10 cases of drought, extreme heat, floods, landslides, storms, and wildfires, respectively. Natural disasters impacted 68.5 million people in 2018, with foods, storms, and droughts (CRED 2019).

1.3 Current Scenario of Adaption and Mitigation of GHG

UNFCCC has previously defined two approaches to addressing climate change: first, mitigation of climate change and, second, adaptation to climate change consequences (Klein et al. 2005; UNFCCC 2009) along-with enhancing resilience and adjusting to the effects of rising temperatures (adaptation) (IPCC 2001).

The Green Climate Fund (GCF), a key component of the Paris Agreement, is the world's biggest climate fund, with the goal of assisting developing nations in raising and realizing their Nationally Determined Contributions (NDCs) objectives for low-emission, climate-resilient pathways in their National Action Plan (NAPs). The NAPs is a dynamic policy tool that will needs to be evaluated, renewed, and improved on a regular basis in response to the dynamic of climate change. About 126 of the 154 developing nations are working on developing and implementing NAPs. The GCF is supporting 58 developing nations out of a total of 126 in developing their NAPs. Of the 22 developing nations, six, which are least developed countries (LDCs), had completed their first NAP as of March 2021.

According to GCF's official website, currently in African region, a number of projects are ongoing such as Preforest Congo (the project's goals include increasing agroforestry production, improving market access, and strengthening financial value chains). Ongoing projects in Asia-Pacific region, for example, Pakistan-GLOF, will build 250 engineering structures, as well as introducing modern whether setup to respond rapidly against natural disasters. In Latin American and Caribbean region, projects being implemented are adaptation project in Cuba (using an ecosystem-based adaptation strategy; the project seeks to improve the climate resilience of approximately 1.3 million underprivileged people) and project in Mayan and Guatemala.

2 GHG Emission Source

A pertinent and major challenge eyeballing the world in present times is the climate change coupled with environmental degradation (Grimsted et al. 2021). This is mostly accounted to the indiscriminate emission of greenhouse gasses (GHGs) in to the atmosphere (Wajid et al. 2007; Ahmad et al. 2009; Usman et al. 2009; Nasim et al. 2010; Burrell et al. 2020). GHG concentration from past various decades is rising. But the present level of GHGs in our atmosphere has increased to an alarming level. Globally, fossil fuels for generating electricity, transportation, and heat are the biggest source of greenhouse gas emission (Ritchie and Roser 2020).

2.1 Emission from Transportation

Transportation sector involves goods movement and people by trains, car, trucks, airplanes, ships, and other vehicles. The dominant form of GHG emitted in this sector is the CO_2, but nitrous oxides, methane, hydrofluoric carbons, and methane are also generated into the atmosphere. These gasses result from the burning of fossils like gasoline, natural gas, etc. (Shahid et al. 2014).

Presently, transportation is accounted for about 29% of the total greenhouse gas emission in the whole world. This makes it the single largest contributor of GHG emission and contributor of environmental pollution. This phenomenon is acute particularly in metropolitan cities of developing countries where there is an increasing demand of vehicles with growing needs of population. By 2050, A majority of world's population is projected to migrate from rural to urban areas mostly in developing countries. This high population concentration and activities could contribute severe traffic overcrowding and exasperate pollution with increasing vehicle ownership in developing economies (Li et al. 2020).

2.2 Electricity Production

Electricity sector is involved in generating, transmitting, and distributing to electricity industrial and residential areas. Electricity is produced using ignition of fossils, that is, natural gas, coal, and oil. During this process, large amount of GHGs specifically CO_2 and N_2O is released in to the atmosphere (Khan 2019). Electricity generation from coal is the most dominant source of CO_2 emitter globally. About 57% of the total energy generated comes from burning coal. The CO_2 emitted from burning coal is far greater than burning natural gas or oil (Khan 2019). The world from nineteenth century has been widely using fossil fuels for their energy consumption. These fossil fuels such as petrol, natural gas, and coal for thousands of years are present as organic matter in the earth. As the time has passed, the generation of energy and its usage has continued to increase releasing more pollutants and hence

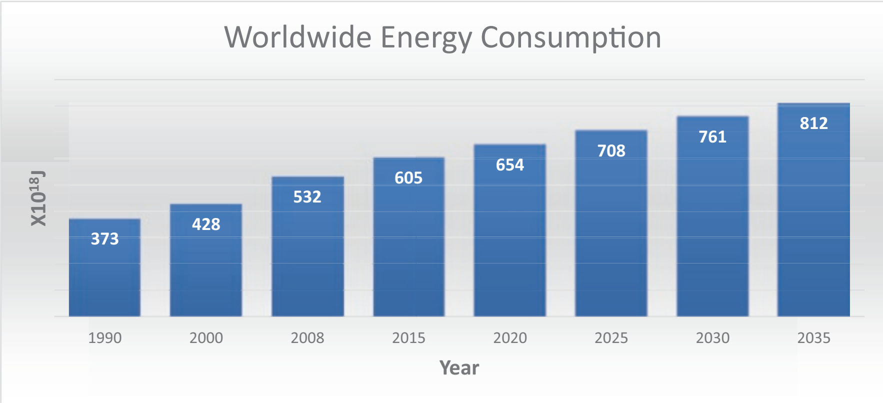

Fig. 1 Energy consumption and projections at Global level 1990–2035. (Modified and adapted from US Energy Information Administration 2011)

warming the atmosphere (Smith et al. 2013). Energy consumption at global level 1990–2035 is shown in Fig. 1.

2.3 *Domestic and Commercial*

Domestic and commercial sectors emit GHGs in two forms. One of them is (a) direct emission, and the other (b) is indirect emission. Fossil fuel combustion, solid waste, and waste water are sources of direct emissions resulting considerable amounts of CO_2, N_2, O, and hydrofluorocarbons. While the indirect emissions usually occur offsite, but mostly are associated with the use of electricity in the domestic and commercial sectors (Zhang et al. 2017). A few estimates have shown that emissions from natural gas consumption raised to about 80% of the fossil fuel emissions resulted from commercial and domestic sector in 2019. A few studies showed that landfills in large metropolitan cities mostly in developing countries have been adding 20% of GHGs annually (Goldstein et al. 2020). Cities are major contributors to climate change, according to UN studies; about 79% of the world's energy is consumed by the cities and production. Though cities account for less 2% of the earth surface, yet they manage to produce more than 60% of GHGs, thus warming the earth substantially (Bulkeley and Broto 2013; Amin et al. 2018a, b).

2.4 *Industry and Industrial Processes*

GHGs emitted from industries and its related processes are frequently on the rise, thus enhancing global warming. Industries are responsible for major emission of CO_2 and other pollutants degrading both air and water (Schlichting 2013). Since

1970, GHG emission from industries in the form of gasses and waste water has nearly doubled. Direct emissions in the form of CO_2 from industries had the lions share having 5.3 giga tons. The indirect emissions from electricity production and heat production released about 2.6 giga ton of CO_2 (Ritchie and Roser 2020). Asian region is the most dominant GHG emitter in the global scenario having one of the fastest emissions in between 2005 and 2010. The rapid development of industrial sector has led to an increased pollutant discharge. Various estimates in China alone show that industrial solid waste of only four industries reached 3.12 billion tons that was responsible for 95.2% of the total wastes (Liu et al. 2017).

2.5 Wastes and Wastewater

Wastewater resulting from commercial and even domestic sector is a prime source of gaseous production. Most of the sewers usually are large source of GHG emission. The GHGs that could be found here are carbon dioxide, ammonia, sulphuretted hydrogen, methane, and marsh gas (Golroudbary et al. 2019). This mixture is frequently hanging, conferring to the degree of putrefaction of the filthy matters that formulates sediment and a slimy coating in sewer pipes (Gomes et al. 2008).

Methane is the primary GHG emitted from the wastewaters. It is directly resulted during anaerobic decomposition of organic matter in the sewers. Nitrous oxide and nitric oxides are the other main GHG emitted. It is often associated with breakdown of nitrogenous-rich compounds such as protein and urea (Allen et al. 2013). Carbon dioxide is mainly related to two main factors, that is, consumption of electricity and treatment processes.

In the sewage water during anaerobic processes, methane and carbon dioxides are also produced, which are then released in to the atmosphere. Emissions of volatile organic compounds (VOCs) occur around entire wastewater cycle (Golroudbary et al. 2019). VOC production in sewers happens during tempestuous flow and air exchange among atmosphere and wastewater (Gomes et al. 2008).

2.6 Agriculture, Forestry, and Land Use Pattern

The Intergovernmental Panel on Climate Change (IPCC) provided recent estimate of global food-system emissions, attributing between 10.9 and 19.4Gt CO_2-equivalent (CO_2e) emissions per year, corresponding to 23–39% of total anthropogenic emissions (IPCC 2019), with industrialized countries emitting 27% (or 4.9 (95% CI 3.7 to 6.4) Gt CO2e yr1) and developing countries (including China) emitting the remaining 74% (or 13 (95% CI 10 to 15) Gt CO2e yr1) (Crippa et al. 2021).

Internationally, it was observed 15% increase in carbon output from the use of energy (heat, electricity, and fuels) in the farming sector particularly in comparison to 1990, with the greatest increase occurring in developing regions (a 50% increase) such as Latin America, Asia, and Africa because agricultural production has become more mechanized, including the increased use of fertilizers and pesticides; emissions have increased in these economies.

3 GHG Emission Management

GHG emissions are the sum of different GHGs and their corresponding GWPs, which shall be described by CO_2e. GHG emissions are determined by multiplying GHG activity data (e.g., gigajoules (GJ) electricity consumption for a furnace) with emission factors (EF) (e.g., CO_2 emissions per GJ/natural gas). The unit of measurement is metric tons, and all GHG emissions are converted to tons of CO_2e, using the 100-year GWP factors (IPCC, 2007).

3.1 Need for GHG Emission Management

To avert climate change, we must decrease the concentration of GHGs present into the atmosphere. GHG levels have been rising over the past 150 years because of fossil fuel combustion and deforestation and forest degradation. Stopping the growth of GHGs can be accomplished in two ways: we can stop adding GHGs to the air, or we can enhance the Earth's ability to draw GHGs out of the air. A global issue necessitates a global solution. A successful solution necessitates the participation of all countries. GHG sources, emissions, measurements, and management must all be understood in order to capture, utilize, reduce, and store GHG. Countries have pledged to keeping warming far below 2 °C and pursuing measures to restrict it to 1.5 °C over preindustrial levels by the end of the century under the Paris Agreement (Paris Agreement 2015). To meet this objective, global emissions must reach a peak as soon as feasible and then fall to zero by the end of the twenty-first century.

3.2 GHG Emission Management Systems

A GHG Emissions Management System is a collection of procedures and technologies created by organizations and adapted to their needs for understanding, quantifying, monitoring, reporting, and verifying GHG emissions. Different mechanisms have been initiated by united nation time to time for quantifying, monitoring, reporting, and verifying GHG emissions. These programs at global level for GHG accounting mechanisms including Clean Development Mechanism (CDM), Joint Implementation (JI) track I & II, Regional Greenhouse Gas Initiative (RGGI), Climate Action Reserve (CAR), Verified Carbon Standards (VCS), Gold Standard (GS), American Carbon Registry (ACR), Alberta Offset System (AOS), and Pacific

Carbon Trust (PCT) running by different parties and countries (Uddin and Holtedahl 2013; Nasim et al. 2018).

To deal with the severe impacts of rapid global warming, governments should coordinate laws, regulations, and tools to better limit GHG emissions. Environmental protection and even GHG emissions are controlled in many areas of a country's laws and regulations. Countries have focused on decreasing GHG emissions for a variety of reasons, the most important of which being climate change. The adoption of new laws and norms is one of the most crucial stages in this process. Focusing on nations with higher GHG emission rates and analyzing the steps done to regulate the situation to minimize GHG emissions is essential. Emissions are governed by a set of laws and regulations. As a result, the top emitting nations may be used to identify laws and regulations, and the countries' GHG emissions performance over time can be compared to evaluate if the policies are successful.

3.3 Classification of GHG Management Policies

The broad array of national policies and strategies that governments may adopt to reduce GHG emissions continues to be reflected in climate change literature. These include regulations and standards, tradable permits, taxes and fees, subsidies, financial incentives, voluntary agreements, information tools, and research and development programs. Policies affecting foreign direct investment, consumption, commerce, and social development goals can all have an impact on GHG emissions.

4 Policies and Implications to Mitigate GHG Emission

4.1 Technologies, Strategies, and Policies to Manage GHG Emissions

There are three major mitigation approaches present in the literature, that is, decarbonization technologies, carbon capture, storage and utilization technologies, and radiative forcing geoengineering technologies (Fig. 2). These approaches along with some other important ones are discussed below.

4.1.1 Decarbonization Technologies

Mitigation efforts using decarbonization technologies and methods, that is, fuel switching, efficiency gains, renewable energy, carbon capture storage and usage, and nuclear power, are conventional. These technologies are well recognized with a manageable degree of risk (Victor et al. 2018; Bustreo et al. 2019). Energy-related

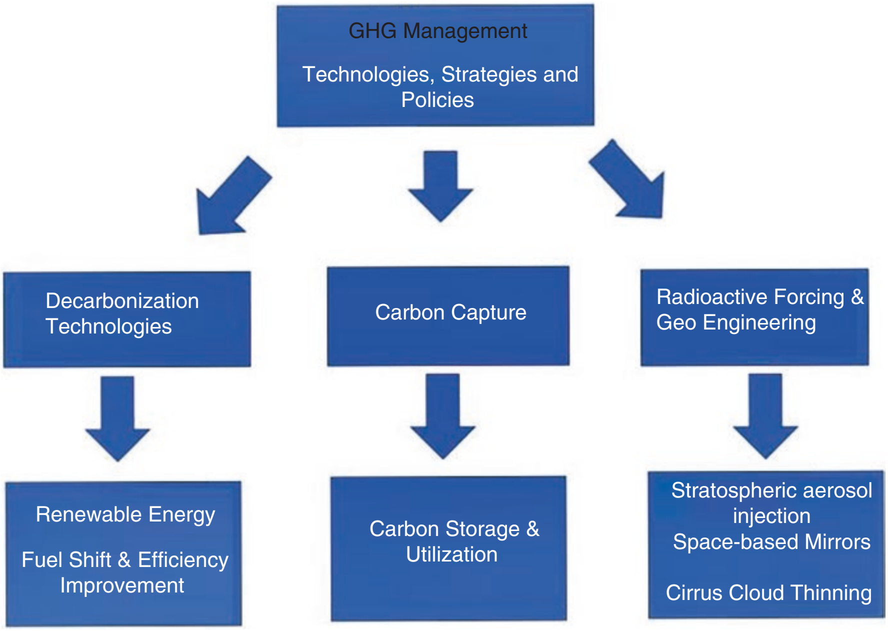

Fig. 2 GHG management strategies

emissions are the primary source of growing GHG levels in the atmosphere, and conventional mitigation techniques and efforts should concentrate on both the supply and demand sides of the energy equation (Ricke et al. 2017). Mitigation strategies that have been studied in various researches include methods that are applied in industry, transportation, and building sectors (Fawzy et al. 2020).

Nuclear power, renewable energy, carbon capture and storage, and a shift to low-carbon fuels like renewable fuels and natural gas can all help reduce emissions (Bataille et al. 2018). Furthermore, efforts to reduce demand include energy-efficient procedures and sector-specific technologies that lessen energy feasting. It also utilizes end-use fuel switch from fossil fuels to renewable fuels and helps integrating renewable power technologies within the energy matrix of such industries (Waisman et al. 2019).

4.1.2 Renewable Energy

A recent worldwide survey on green energy showed that the proportion of renewables in the total final energy consumption globally was estimated at 18.2% in 2018 (Now 2019). The literature offers a variety of contemporary renewable energy technologies for consideration (Chel and Kaushik 2018). Renewable energy has the potential to supply a significant proportion of the world's power. According to Now, in terms of electricity production, green energy accounts for approximately 27.2%

of global power generation as of 2018 (Now 2019). Wind power's share of the US energy production was roughly 5.5% in 2015, whereas hydropower accounted for 15.8%. The capacity of photovoltaic solar power and onshore wind power has grown significantly during the last decade, although there has been an exceptional amount of growth in big-scale hydropower generation capacity. By the end of 2019, solar power's global installed capacity had reached 505 GW, up from 16 GW in 2009. In terms of wind energy, 591 GW of worldwide capacity was recorded in 2019 as opposed to 121 GW in 2009 (Now 2019; Katzner et al. 2019; Murdock et al. 2021).

The potential benefits of carbon reduction through renewable energy deployment are enormous. Renewable energy projects should be prioritized in the development process. Policy instruments, financial support, and accessibility are all areas that will help speed up the shift to a reduced carbon economy. Market-based incentives for project developers are also important (Campos-Guzmán et al. 2019).

4.1.3 Fuel Shift and Efficiency Improvement

The shifting of electric sector from conventional energy sources into green energy resources in coming future is discussed in the literature as an effective approach in shifting toward a reduced carbon economy in coming years (Wendling 2019). The transition to natural gas is also relevant to the industrial, transportation, and construction sectors; however, as previously said, a switch to clean fuels is a more long-term solution that will provide even greater decarbonization potential in these industries (Plessmann and Blechinger 2017).

Many opportunities exist in the business sector for efficiency improvements. Waste heat can be recovered from steel and cement processes for power and heat production on the site via waste heat-driven power plants in utilizing exhaust gases to produce electricity (Plessmann and Blechinger 2017). Steam pressure can be used to generate electric power for energy consumption on the site. Back pressure steam turbines can significantly improve energy efficiency when applied in locations where steam pressure reduction is required (Wendling 2019). Turbine expanders may be used in applications where gas pressure reduction is necessary, but the same method may also be employed to increase power production. Micro- and small gas turbines can be used to generate onsite heat and power from waste gases from industrial processes (Andrei and Sammarco 2017).

4.1.4 Carbon Capture, Storage, and Utilization Technologies

Carbon capture and utilization (CCU)—a method for capturing carbon dioxide from industrial processes, converting it to useful chemicals and fuels, while also contributing to climate change reduction—has begun to attract worldwide attention (Gabrielli et al. 2020). One of the benefits of CCU over CCS is that CO_2 usage is typically a profitable process. Furthermore, carbon dioxide is a "renewable" resource (as long as it is produced by various industrial activities), inexpensive, and nontoxic in comparison to traditional petrochemical feedstock (Andrei and Sammarco 2017).

4.1.5 Carbon Capture Options

Electricity generation in fossil fuel power plants is responsible for approximately 40% of global CO_2 emissions (Wood and Roelich 2019). As a result, these supplies are major contenders for a possible CCS or CO_2 utilization application. The capture of CO_2 owing to the variety of industrial processes that produce it is impossible with a one-size-fit-all technology because it varies from process to process. CO_2 capture systems are available in a variety of forms and sizes to ensure compatibility with various industries. The degree of maturity among CO2 capturing technologies, on the other hand, varies across sectors. For example, power plants and oil refineries are moving closer to implementing CO_2 capture systems on a large scale, but the cement, iron, and steel sectors will have to make the leap from small-scale demonstration facilities to industrial use (Andrei and Sammarco 2017).

Globally, there are just two carbon capture and storage facilities currently in working state as of 2018. They have yearly a capacity of capturing 2.5 million tons of CO_2. There are now nine additional carbon capturing projects under developmental stage. They are expected to raise the current capability to 12 mega ton of CO_2 by 2026; however, a noteworthy variance from viable development situation aimed by the international energy agency for 2045 is a capacity of 1498 MtCO2 (IEA 2019).

4.1.6 Radiative Forcing Geoengineering Technologies

Geoengineering techniques modify radiative energy budget of earth to steady or decrease temperatures globally, which is known as radiative forcing geoengineering. Increasing earth reflection capacity by improving shortwave radiations from the sun is reflected to space, which is also known as solar radiation management (Lawrence et al. 2018).

4.1.7 Stratospheric Aerosol Injection

Solar radiation management techniques that aim to simulate the cooling effect of a volcanic outbreak by introducing shimmering aerosol specks into the stratosphere are called stratospheric aerosol injection (Lawrence et al. 2018; Zhang et al. 2018).

The reduction in temperature with this technique is likely to be between 2 and 5 W/m^2, according to modeling and previous volcanic eruption data (Lawrence et al. 2018). Smith (2020) explored various methods as well as its costs during the first 15 years of placement, which began in 2033. A new purpose-built high-altitude aircraft will be required to deploy stratospheric aerosol injection using an aircraft-based delivery system, according to the researchers. However, even with modifications, current models would not be sufficient for this purpose because of the specialized requirements. The annual cost of this project from its deployment to its working is estimated in the range from $5.5 billion to $7.45 billion (Wagner and Smith, 2018).

4.1.8 Space-Based Mirrors

The literature describes Sunshades employing mirrors in the space as a technique to manage solar radiation that allows reflection of the incoming solar radiation in order to decrease temperatures worldwide. Because this technique is based on complex electronics, it needs to be sent into space using several spacecraft. The reflectors must be carried into orbit where two gravitational fields are in equilibrium thus ensuring reflectors to stay in its place (Fawzy et al. 2020).

While this technique has the potential to create a significant lowering in temperature based on model studies, such technology is still in its early stages of development. The main disadvantage of this technique is that transporting materials into space becomes prohibitively expensive. Material costs must be reduced to less than $100/kg in order for this technology to be economically feasible (Lawrence et al. 2018).

4.1.9 Cirrus Cloud Thinning

Thinning of cirrus clouds is a worldly radiation management strategy that goals to boost surface-based long wave radiation and thus stabilize or reduce global temperatures. Clouds of this type are responsible for the planet's radiation balance, influencing the earth's water cycle and temperatures. These clouds absorb and reflect solar radiation. They produce a net warming effect owing to the inequity between received and departing radiative forcing (Kärcher 2017).

According to model imitations, the maximum cooling impact of this technique has been projected to be between 2 and 3.5 watts per square meter (Lawrence et al. 2018). There is no documented projection of estimated costs for cirrus cloud thinning, and further study is required to comprehend side effects as well as investigate possible delivery methods (Lawrence et al. 2018).

4.2 Factors Affecting Applicability of the Policy and Implications

A growing number of local administrations are accepting policies, programs, and procedures to address climate change challenges. However, progress varies widely from country to country (or even between different policy areas in the same city).

Climate policy researchers and activists highlight the continuing gap between political realities and political discourses, which in many cases focus on the significance of local action to climate change (Huang et al. 2019).

Here, we present some key factors that affect the application of the climate policy in the community.

4.2.1 Capacity of the Local Government

There is a wealth of literature that emphasizes the importance of the ability of various local governments to account for regional climate policy development. In this literature, we can distinguish between analysis that focuses on the legal capacity of local governments and those that focuses on economic and administrative resources (Zimmermann 2018; Yildirim and Onder 2019).

For example, in China's Rizhao metropolis, the local administration actively promoted sun power, which includes the responsibility of all new buildings in the metropolis' jurisdiction to put in sun water-warmers. Solar water-warmers at the moment are used by honestly all families in valuable regions of the metropolis after 15 years of neighborhood rules encouraging (Huang et al. 2019). As this situation demonstrates, local governments with an obligation to control waste disposal, transportation, and power can be capable of doing extra than different local authorities (Zimmermann 2018).

But, in many situations, urban changing climatic issues require government action that goes beyond the statutory powers of local authorities. The "fit" problem (Romero Lankao 2007; Bulkeley and Broto, 2013) is related to the discrepancy amid the size of the urban problem to be regulated and the powers of local governments (Di Gregorio et al. 2019). The capability of local administrations to implement climate change mitigation strategies in specific policy areas will depend on existing urban authority structures (Zimmermann 2018).

4.2.2 Organizational Resources

There are three types of organizational means that have a significant impact on the ability of local governments to apply climate policy. This is information management human resources and money. A study by Hofstad and Vedeld (2020) comparing regional climate policies in Cape Town and Johannesburg illustrates this point. According to the study, regional programs to reduce greenhouse gas (GHG) emissions have been more successful in Cape Town than in Johannesburg. The municipality of Johannesburg has had only few officials' responsibility for climate change policies and environmental initiatives, while the Cape Town office has a wealth of manpower and funding to successfully implement mitigation measures. About 77% of cities surveyed showed lackness of funding for its execution is a major problem with their climate policies, and about 67% of cities shortage of funding hampers their hiring of new staff to combat climate change reported.

4.2.3 Local Framing

Some researches discuss that the prioritization of climate goals is dependent on the alienation with the socioeconomic interests of government and people. Urban communities and local governments have more chance to develop and promote climate-friendly policies if they can be formulated with local concerns in mind, resulting in additional socioeconomic or environmental benefits (Thomson and Newman 2020). In this sense, questioning is an important factor not only in terms of policymaking (e.g., the goals to be achieved and the types of outcomes the program is expected to produce) but also in determining whether the policy is actually implemented (Romsdahl et al. 2018). It is feasible or likely to be implemented.

There are a number of studies that support the claim that putting the problems and co-benefits in a favorable light is beneficial for climate change mitigation in cities in underdeveloped and developed countries. For instance, a study in Mexico City by Mauad (2018) found that climate action teams formulated climate change policies as part of a larger plan to reduce air pollution and improve air quality, which had previously been on the political program.

4.2.4 Organizational Factors

Empirical studies support cities advocating the fight against climate change, integrate it into local politics, and encourage local governments in international networks of local governments (such as ICLEI and C40) and local governments. Emphasizing the importance of participating in local committees/forums, the government provides supportive regulatory measures (Bulkeley and Broto 2013; Ryan 2015). Regarding the regulatory framework, the existence of regional climate protection legislation may suggest support for climate issues and some degree of politics, but climate change is necessarily part of the political debate, and concrete evidences are available (Broto 2017).

This is the case for some cities in the Southern Hemisphere (e.g., Mexico City and Buenos Aires), where empirical studies show that the changeover from urban climate planning to action depends on the gap between political discourse and political reality (Ryan 2015). Administrative procedures and practices also have a significant impact on the likelihood of implementing adaptation measures in a city (Uittenbroek et al. 2019).

Second, the reciprocity of climate change responses means that a single sector cannot take action to effectively address the problem. Dividing responsibilities within joint bureaucrats is also an important aspect, often making effective cooperation, information exchange, and collaborative action among co-employees more difficult (Aylett 2015).

4.2.5 Staff, Information, and Financial Resources

Various studies have emphasized that human resources, funding and access to information, are important features in promoting climate policy adaptation. Given the comprehensive nature of effective response to climate change, integrated action is needed to strengthen staff expertise in several planning and operational processes in key areas (Bulkeley and Broto 2013).

Mainstreaming climate policy adaptation effective intervention also needs information. There is usually very limited information on possible climate impacts on particular urban areas and a socioecological susceptibility assessment that provides effective adaptation policies (Li and de Oliveria 2021). In terms of monetary resources, various studies emphasizes the association between investment and the obtain ability of financial resources to reduce vulnerability to extreme events and make better preparations (Serrao Neumann et al. 2018).

4.3 Criteria for Evaluating Policies and Instruments

4.3.1 What Is Policy Evaluation?

Evaluation of the policy might illuminate and further develop strategy advancement, reception, execution, and adequacy and construct the proof base for strategy intercessions (Crabb and Leroy 2012).

Only recently has the practice of evaluating environmental effects become popular in the field of environmental policy. Decision-making processes have long been an important part of environmental management, although this particular area has only lately gained popularity (Crabb and Leroy 2012; Vogl et al. 2021).

4.3.2 Criteria for Policy Evaluation

Criteria for climatic policy evaluation are a set of questions, concepts, and ideas that help to evaluate the effectiveness of climatic policies. The criteria are divided in three parts: effectiveness, efficiency, and equity. It is suggested that climate policy should be efficient and equitable to ensure a long-term sustainable development for the society (Vogl et al. 2021).

(i) *Effectiveness*
   Effectiveness of policies focuses on making progress toward specific goals in a real sense, such as stabilizing greenhouse gas (GHG) emissions within a

specified period. While this criterion focuses on whether the goal has been met, it does not take into account how much effort was put in reaching the goal (Vogl et al. 2021). Therefore, this set of criteria does not consider opportunity costs and instead evaluates only whether the desired result was achieved despite these opportunity costs. A way to measure if GHG emissions were stabilized would be to compare total GHG emissions today with what they would have been had no climate policy been implemented (Baker et al. 2012).

(ii) *Efficiency*

Efficiency focuses on achieving the desired results with minimal resources, for example, by avoiding opportunity costs. Opportunity costs are the benefits that could have been generated but were not because resources were used elsewhere; hence, resources are inefficiently allocated to achieve the same result (Wamsler et al. 2020). For example, if GHG emissions are stabilized without any climate policy then society has saved resources, which can be used elsewhere (opportunity cost). The opportunity cost is illustrated in this case as lost benefits or missed opportunities instead of costs that must be paid. Economic costs and environmental impacts associated with implementing a certain measure can also be considered in evaluating policies for their efficiency (Baker et al. 2012).

(iii) *Equity*

Equity assesses the distributional effects of policies and how beneficial or harmful their outcomes are for different types of interests, groups, and individuals. Therefore, while effectiveness focuses on actual results and efficiency focuses on achieved results, this criterion evaluates the fairness of such results (Guglyuvatyy 2010). Since there is limited knowledge about who will be affected by climate change in the future, attempts to optimize equity over efficiency and effectiveness may result in lower short-term benefits. Equity therefore requires that we consider cumulative costs into future generations that might result from reduced GHG emissions (Baker et al. 2012). This means that one should consider economic and environmental impacts for all agents involved in decision-making processes.

Finally, taking into account how beneficial or harmful certain policies are for different types of interests, groups, and individuals can be used as a measure for equity. All this information can help to draw conclusions about the overall change in welfare resulting from implementing a certain climate policy and whether it can be judged as socially optimal (Guglyuvatyy 2010).

4.3.3 Policy Evaluation and Time

In terms of environmental policy evaluation, the time dimension is essential in a variety of ways. It is first and foremost processes, particularly in the environmental sector that may take place over extended periods of time. Effects created by legislation, including those influenced by policies, will not be seen for many years: this is known as the time lag effect. In the case of environmental policy, we may be talking about a period of years (Doukas and Nikas 2020).

The influence of a single policy measure is nearly impossible to isolate from its surroundings. And yet, in policy evaluation, the introduction of a new plan or tool, a change in government, the end of a budget cycle, or another landmark such as this are often regarded as the boundaries of a policy period. In order to obtain "pure" analysis, it is necessary to establish an intentional and clear timetable (Hildén et al. 2014).

4.3.4 Spatial Dimension

In policy evaluation and data gathering, a single spatial dimension is usually considered only: for example, a national or subnational administrative level. Similarly, state of the environment reports and similar environmental assessment reports frequently focus on regional circumstances to some degree owing to data scarcity without considering any harm that this region may be causing across the world. The popular "ecological footprint" approach and its many variations attempt to include these effects; yet, because of data constraints and (inevitable) methodological reductionism, the accuracy and dependability of these methods are still doubtful (Scrieciu et al. 2014).

As a result, an environmental policy assessment at the national or subnational level could provide a misleading impression. Policy evaluation, on the other hand, must be done at a scale that is relevant to the problem. As a result of this, policy evaluation must apply to an area where there is enough administrative capacity to address the issue effectively (Huang et al. 2019).

4.4 Evaluation of Climate Change Adaptation Projects

Adaptations to change are not new, and human beings have been modifying their environments for ages. Throughout history, people have adjusted to climate change and variability. However, due to large amounts of man-made greenhouse gases now in the atmosphere, Earth's temperature is 0.8 °C higher than it was before industrialization, droughts are more frequent and intense, and seas are rising. As a result of these points, many regions across the world are facing significant health risks as a result of climate change. To adapt natural, architectural, social, and economic systems, proactive response is required as a consequence of this confluence of circumstances (Zhao et al. 2018).

There are three types of responses to climate change that have been identified by Eakin et al. (2009), which are as follows:

(a) Social vulnerability approach, which aims to address underlying social problems.
(b) Resilience approach that focuses on improving a system's resilience.
(c) Actions to particular climate change hazards.

4.4.1 Renewable Energy Technologies (RETs)

It is recommended to use various renewable energy sources to solve the anthropogenic effects of greenhouse gases on the surrounding environment (al Irsyad et al. 2019). Renewable energies, including solar, wind, hydro, biomass, and geothermal energy will have an increasingly important part in the in the future's energy mix, leading toward adaptation and mitigation from climate change (Owusu and Asumadu-Sarkodie 2016).

Geothermal energy is suitable for mitigating climate change because it can generate electricity regardless of the season and is efficient in network construction (both on/off) (Bromley et al. 2010). Th eliterature indicates that the use of geothermal energy can bring important benefits to climate change adaptation in developing countries. Solar power is the most available renewable energy source. It provides a wide range of services including drying, cooking power generation heating, and water treatment. Solar energy use is increasing, with several pilot projects being field tested in several emerging nations (Ondraczek 2014).

4.4.2 Developed Country Perspective

The most severe effects of climate change will fall on the poorest nations, yet the developed world will not be immune (Owusu and Asumadu-Sarkodie 2016). Climate change's influence on economic growth in the developed world, including access to vital resources such as water, food, and energy, is already evident. Water scarcity is increasing in areas where water has previously been plentiful, such as the Mediterranean Basin and parts of the United States (Ciscar et al. 2019).

This would cause additional carbon to be released into the atmosphere, exacerbating climate change. Extreme events are on the rise, which means that infrastructure damage and faster capital depreciation are more likely than before. In other words, developed nations will be particularly harmed by increases in extreme events because they invest a significant amount of money each year in fixed capital (Hatfield et al. 2020).

5 Conclusion

An anthropogenic affiliation with warming climate is the number one cause of global climate change. A wide recognition of climate emergency necessitates immediate adoption of workable mechanism for mitigation and adaptation. Three main approaches, decarbonization technologies, carbon capture, storage and utilization (CCUS) technologies, and radiative forcing geoengineering technologies of tackling climate change, have been discussed in an extensive literature covered in this chapter. It is worth mentioning here that to no single approach or technology alone can viably tackle climate change and that combination of all technologies and techniques discussed in this review should be implemented (if proven to be technically and economically feasible). This chapter also discussed the factors involved in applicability of climate policy and implications. The review found a continuing gap between political realities and political discourses, which in many cases focus on the significance of local action to climate change. Importance of local government capacity is emphasized to be a major contributor and accountable for regional climate policy development. Policy evaluation is an undermined topic, also briefly explored in this review, suggesting it to be important as on the basis of which recommendations are generated.

An efficient and an aggressive drive toward negative emission policies, technologies, and projects should be formulated. For this, appropriate policy instruments must be utilized by the policy makers. Governments must propose and implement such frameworks having special focus on limiting carbon use and moving toward green energy. It is recommended that efficient market-based mechanisms must be introduced in order to incentivize various project developers to introduce and set up carbon removal projects.

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Concept of Climate Finance

Syed Tauqeer Ahmad, Abida Hanif, and Fahad Nuzair Ansari

Abstract The realization of the glaring benefits of environment-friendly sources of energy has rejuvenated global interest in renewable energy sources. The transition from traditional sources to renewable or environment-friendly sources could be a $90 trillion capital-intensive undertaking by 2030, as per World Banks' estimate. This chapter discusses the broader concept of climate finance, different private and governmental avenues of financing available, and the burgeoning disparity between the developing world and the developed world, on climate financing. The grave situation turns grim when we find out that developing countries spent $71.2 billion in the year 2017 against the total estimated need of $474 billion. The gap of approximately $300 billion would remain intact despite the commitment of $100 billion by United Nations Framework Convention on Climate Change (UNFCCC). The gap has been increasing consistently because developed countries don't contribute in proportion to their contribution to environmental deterioration. China with 26.1% emission turns out to be the biggest emitter of greenhouse gases (GHG), ensued by the United States (13.4%), the European Union (7.6%), India (6.5%), Russia (5.6%), Japan (2.6%), and Brazil (2.1%). The vast disparity between involvement in environmental degradation in the form of CO_2 per person by a handful of countries and their contribution to mitigating the effects demand a justice lens. To bridge this ever-widening gap, it is suggested that governments of developing countries should explore ways to increase public-private partnerships through tax incentives and other appropriate measures. An optimal climate finance system should not only earmark a substantive amount of capital stock, rather the overall objective of the system should be the development of a just climate finance mechanism with built-in channelization of the flow of capital.

Keywords Disparity · GHG · Per-capita CO2 emission · Modes of finance

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_9

1 Introduction

Air quality and health have deeply embedded albeit inverse relationship with health and ensued productivity. Phrased straightforwardly, it can be said that poor air quality leads to poor health that in turns lead to lower productivity. This trilateral nexus of pollution, health, and productivity has rejuvenated and revived the interest in mitigating the effects of pollution. The vicious cycle of productivity is the prime reason for poor air quality as manifested in Fig. 1. The cycle is based on multiyear experience of the corresponding author and is substantially supported by the empirical evidence. In fact, poor air quality leads to poor health, ensuing in lower productivity that in turn causes lower income, and lower income in turn limits the ability of spending on mitigation and adaptation.

Economic losses are associated with pollution-triggered health issues, which in turn lead to lower productivity stand at $2.9 trillion. In the wake of this, global spending to contain and mitigate the effects of pollution capital flows has continuously been rising. Although these amounts seem sizeable, it falls short of the flows needed to mitigate the effects of pollution and retroactively reconfigure and reengineer the production process to make them environment friendly. In fact, climate finance deals with exploring conventional and innovative ways to bridge the financing gap between the funds available and funds needed (Overland and Sovacool 2020).

Fig. 1 Vicious cycle of productivity

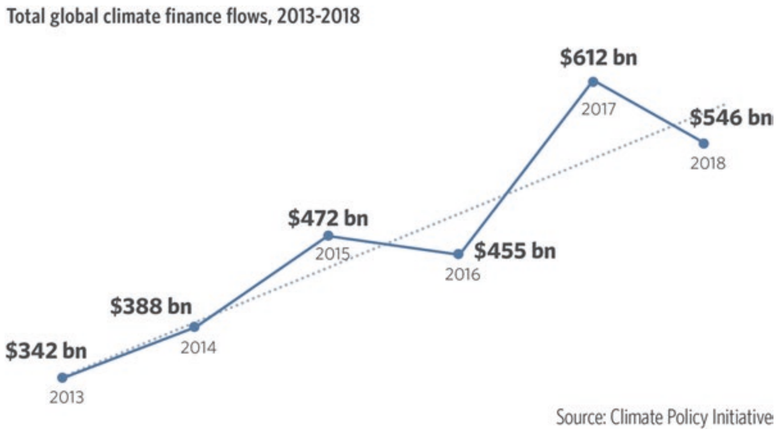

Fig. 2 Total global capital flows 2013–2018

The global climate finance flows show a steady increase from $342 billion in 2013 to $612 billion in 2017 before marginally dipping to $546 billion in 2018 (Fig. 2).

1.1 What Is Climate Finance?

As per UNFCCC, climate finance refers to local, national, or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change. There is a broad scope of divergence and disagreement on the definitional aspect of the idea; however, if we look at underlying sources and objectives points of view, it is fairly straightforward. Essentially, it involves two aspects: (1) the generation of funds and (2) spending or disbursement of funds. As far as the generation part is concerned, it can be local, national, or transnational, and the second part is related to disbursement. The finances should be spent on mitigation and adaptation. Mitigation means taking measures to remove, reduce, or neutralize the hazardous impacts of some action or activity. In our context, we would limit it to the measures taken to reduce the impact of the emission of greenhouse gasses. And adaptation refers to surviving in the environment in a better way.

In the broadest sense, "climate finance involves deploying and diverting funds towards pursuits that diminish the emission of greenhouse gasses and or help communities adapt to climate change effects." The general consensus on the definitional aspect of climate finance converges on ascertaining and filling the financing gap between capital available and capital aimed at containing and reducing susceptibilities resulting from environmental deterioration.

Recently, there has been a drive to fill the financing gap by channeling funds from developed nations to developing nations for mitigation and adaptation purposes as envisaged in Kyoto protocol and Paris Accord.

2 Moving Toward Solution: The Paris Accord

In fact, the Paris agreement is regarded as the first practical step toward reduction in the disparity between the developing and developed world in terms of spending for decreasing pollution and mitigating to minimize its impact on the population.

The Paris agreement was signed in April 2015. Initially, there were 175 signatories, and now this number has increased to 195 (Fig. 3). The Paris Agreement formulated a binding global action plan with the cherished objective of putting the world right on track by avoiding hazardous climate change by restricting global warming to less than 2 °C greater than preindustrial levels. The accord calls for channelizing climate financing by national, regional, and international entities for climate change mitigation and adaptation projects and programs.

Paris Agreement implementation mandates socioeconomic amelioration, by using state-of-the-art technology. Signatories of the accord are required to work on an ambitious 5-year cycle of climate action plans carried out by countries. The final version of the plan that individual nations are supposed to implement by 2022 for climate action is nationally determined contributions (NDCs).

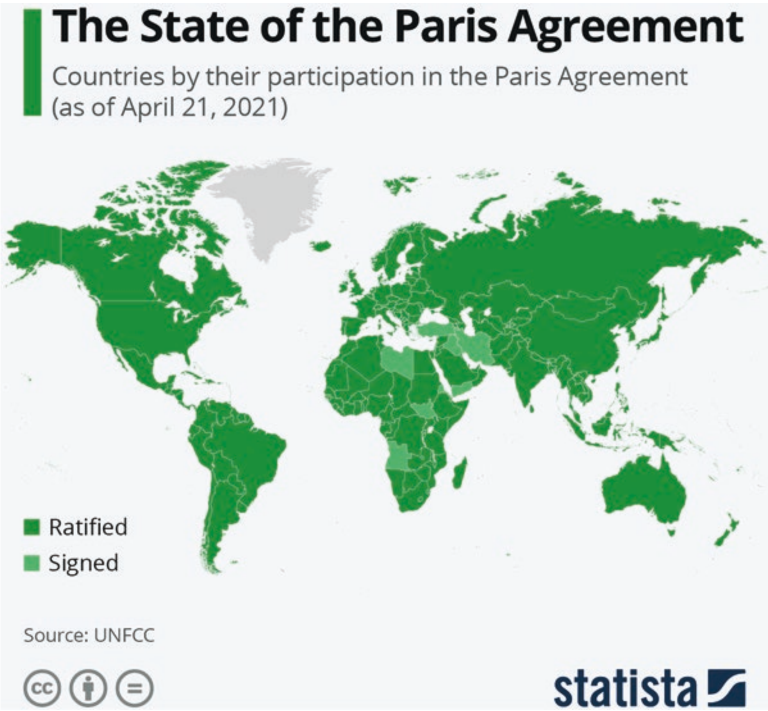

Fig. 3 The participating states in the Paris Accord (as of April 21, 2021)

2.1 Climate Finance Leadership Landscape

With the courtesy and cooperation of various stakeholder groups, the evolution of climate finance has come a long way. Most of the high-impact, formidable undertakings and accords that have led others to take action to invest in climate solutions in an integrated way consist of the following:

2.1.1 United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC went into effect in 1994. It was formed to ask developed countries to lead the way "to stabilize greenhouse gas concentrations at a level that would prevent dangerous human induced interference with the climate system." The UNFCCC strives to get additional funds to launch climate change activities in economically emerging nations (UNFCC 2018).

Industrialized nations agreed to fund climate change activities in developing nations by amassing the additional sum under the auspices of UNFCCC, and this endowment would be essential in addition to any assistance already in place. The financial support includes a mix of grants and loans channeled through the Convention and is managed by the Global Environment Facility (GEF).

2.2 Kyoto Protocol

The Kyoto protocol, as its name suggests, was agreed upon in the city of Kyoto, Japan. Kyoto protocol sets limits on the emission of seven kinds of gasses, whose emission beyond a certain limit can be a health hazard. Although adopted on December 11, 1997, it went into effect in 2005. Realizing the heterogeneity of the capability to combat pollution, with developing countries' very limited capability to combat, laid bigger responsibility on developed nations to take the initiative in restricting the emission of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4)hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Annex A comprised all these seven kinds of gasses. Nitrogen trifluoride was included in Doha round. Annex B of Kyoto protocol sets mandatory emission reduction targets for 37 industrialized countries and economies in transition and the European Union. Overall, these targets add up to an average 5% reduction compared to 1990 levels over the 5 years 8–2012 (the first commitment period). Nitrogen Trifluoride was added in the Doha Round.

The Kyoto protocol lays the groundwork for the adaptation fund, which is part of the protocol's efforts to "facilitate the development and deployment of technologies that can help increase resilience to the impacts of climate change pathway."

2.3 UN Sustainable Development Goals (SDGs)

In 2015, world leaders set 17 high-end goals, later on adopted by the 193 UN Member States, popularly known as Sustainable Development Goals (SDGs) that aim to create a better world by 2030. The broad-based development agenda includes poverty alleviation, reduction in inequality, and most importantly urgency of climate change. Although the prudently developed 17 points Sustainable Development Goals look more like a philanthropists' fantasy at present, it lays down a futuristic shared blueprint for peace and prosperity for people and the planet. The goals 7 and 13 specifically call for affordable clean energy and formidable climate action plan. The action plan has a built-in mechanism to generate finances from diverse sources to achieve the cherished objective by 2030 (International Energy Agency 2011).

2.4 Climate Investment Fund

In 2008, Climate Investment Fund (CIF) was established with an initial capital of $10 billion to expedite climate action by allowing transfiguration through its ongoing projects of clean technology, energy access, climate resilience, and sustainable forests in emergent and developing nations.

The major focus of CIF is to provide financing for capital-intensive, high-risk, long-term projects. Realizing the failure risk often deters the private sector from engaging in any innovative and capital-intensive undertaking, CIF funds such projects in partnership with private investors, communities, and civic societies. With the financial backing of multilateral Development Banks (MDBs), the fund affords low-cost long-term financing for innovative solutions alongside scaling up the proven ones. Besides, CIF finances identifying and tapping into new sustainable markets by rallying private sectors' capital for climate improvement purposes. The unique feature of the CIF is that it rallies collaborators behind zealous climate targets and actions, thereby gathering different set of partners with diverse backgrounds who might be shy of investing alone.

Impartial analysis reveals that CIF has made some substantial progress in the areas of environmental-friendly technologies, energy provision, climate adaptation, and sustainable development. Cashing and capitalizing on the success, the management has identified next-frontier climate challenges in five new areas: departure from coal usage, climate-friendly cities, nature-based approaches, industry decarbonization, and renewable energy integration. During financial year of 2021, the group of seven industrialized nations (G7) pledged around $2 billion in supplementary finances for CIF to meet strong demand emerging from developing countries (Gouldson et al. 2015).

3 Financial Calculus of Climate Finance

Perceptively, the capital investment made in environment-friendly infrastructure yields long-term results with relatively lower return on investment in the short-term. In fact, through climate finance countries, new avenues of opportunities both in terms of monetary and nonmonetary benefits that include job creation and reduction in health-care costs. For example, $1 investment in resilient infrastructure in the developing countries could yield $4 in benefits. This is above and beyond the benefits derived by averting costly healthcare-related expenses, costly repairs, and improvement in productivity. Further, a transition to low-carbon, resilient economies has the potential to create over 65 million new jobs by 2030 (Colenbrander et al. 2018; Zhang and Pan 2016; Schmidt 2014).

The IFC has identified that Nationally Determined Contributions (NDCs) has the potential investment commitments by 21 emerging economies to tune of $23 trillion by 2030.

Overall, the smooth transition from traditional ways of manufacturing to environmental-friendly could involve a hefty capital outlay of $90 trillion by 2030 in terms of infrastructural improvement to ensure its compatibility with climate goals.

4 Types of Sources of Finance

An assessment by International Monetary Fund (IMF) asserts that a base contribution of $120 billion of financial assets by developed nations would entitle the fund to obtain $1 trillion over 30 years and use the proceed to finance $100 billion for climate change actions yearly among developing nations. The provision of concessional financing to developing countries would mandate subsidized resources from developed countries to developing nations' ever-growing diverse funding needs.

The sources of funds can broadly be classified into two categories:

(A) Public actors (government and multilateral climate funds).
(B) Private climate finance.

4.1 Public Actors (Government and Multilateral Climate Fund)

The multilateral climate funds (i.e., governed by multiple national governments) are important for paying out money in climate finance. Diverse kinds of multilateral climate funds bearing different name and purpose are the Global Environment Facility Climate Investment Funds (CIFs), Green Climate Fund (GCF), and

Adaptation Fund (AF). Project support totaling $2.78 billion was approved under these four funds. India turned out to be biggest single-country recipient of the facility, ensued by Ukraine and Chile. On per person basis, Tuvalu turned out to be the biggest recipient of funding, and Samoa and Dominica were the second and third biggest recipient of funds. In monetary terms, the United States is the biggest contributor across all forms of funds, while on contribution relative to population size, Norway came up with the largest contribution. Most multilateral climate funds use diverse mix of financial instruments, such as debt, equity, grants, and other risk reduction options. Among these four funds, at present, the Green Climate Fund with $10.3 commitments from 49 countries stands ahead of other funds in terms of pledges as well as disbursements (Reyes 2013).

4.2 Private Climate Finance

Lower-risk aversion, higher investment needs, coupled with adoption of unproven technologies often deters the public sector involvement and necessitates the participation of private sector to fill the vacuum. If countries want to unleash the full potential benefits of this financing facility, it is imperative to look at the full landscape of funding options along-with must-have to determine the optimal mix of resources (Buchner et al. 2011). Retrospectively, the urban infrastructural projects with adequate return on investment is expected based on project income flows, or low-risk government debt repayments make attractive option for private investors (Floater et al. 2017). The prerequisites to attracting private finance are creditworthiness and Banks' ability. Big chunk of private investment in climate finance comes from investment companies, commercial banks, pension funds, insurance companies, and sovereign wealth funds. The diverse investor types can have heterogeneous risk-return projections over investment time horizons; therefore, projects should be tailored accordingly.

At times, financial constraints mandate private public partnership. Governments can partner with private investors in wide variety of ways including equity, grants, and debt, which are any other mean of risk reduction instrument like guarantees. Governments often use some of these instruments as part of sovereign wealth fund. Figure 4 depicts the investment by world nations in climate finance, through public/private and mitigation/adaptation.

Figure 4 shows a clear pattern that in the United States and Canada, overwhelmingly big proportion of climate finance comes from private sector, whereas in the case of sub-Saharan African countries, it is vice versa. The private and public contribution in case of Europe is 50/50.

Figure 5 depicts that quantum of private sector for climate financing has been steadily increasing over the years and has outpaced the public contribution (UNCC 2022).

Figure 6 shows how governments and capital markets interact together to generate and channelize climate finance.

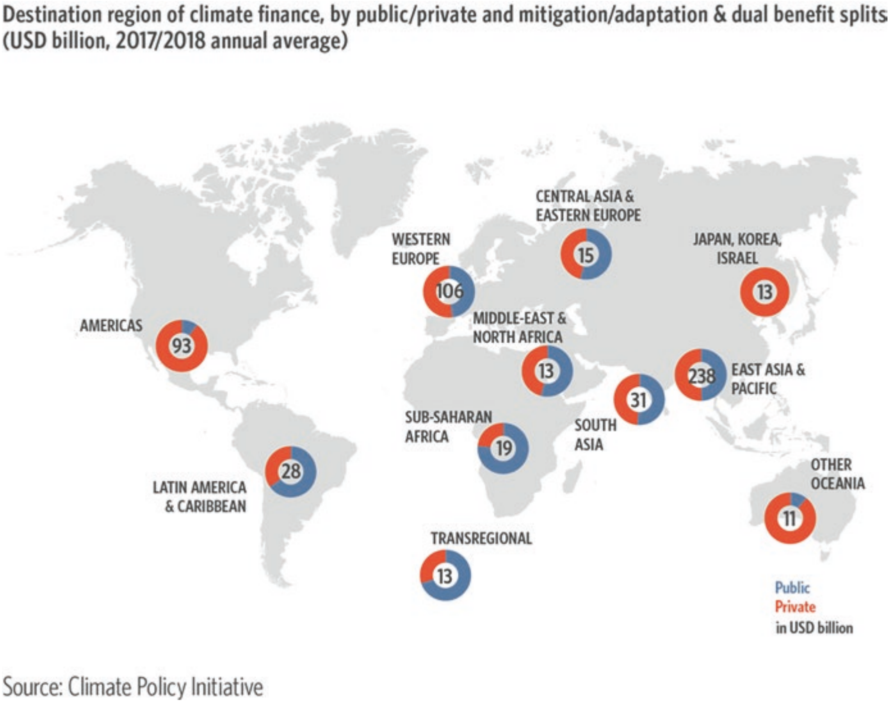

Fig. 4 Investment in climate finance, through public/private and mitigation/adaptation (2017–2018 in USD billion)

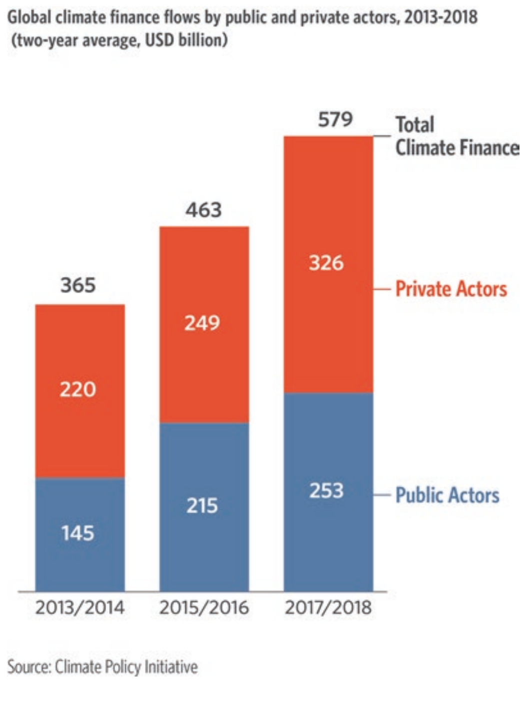

Fig. 5 Global climate finance flows by public/private, 2013–2018 (2-year average in USD billion)

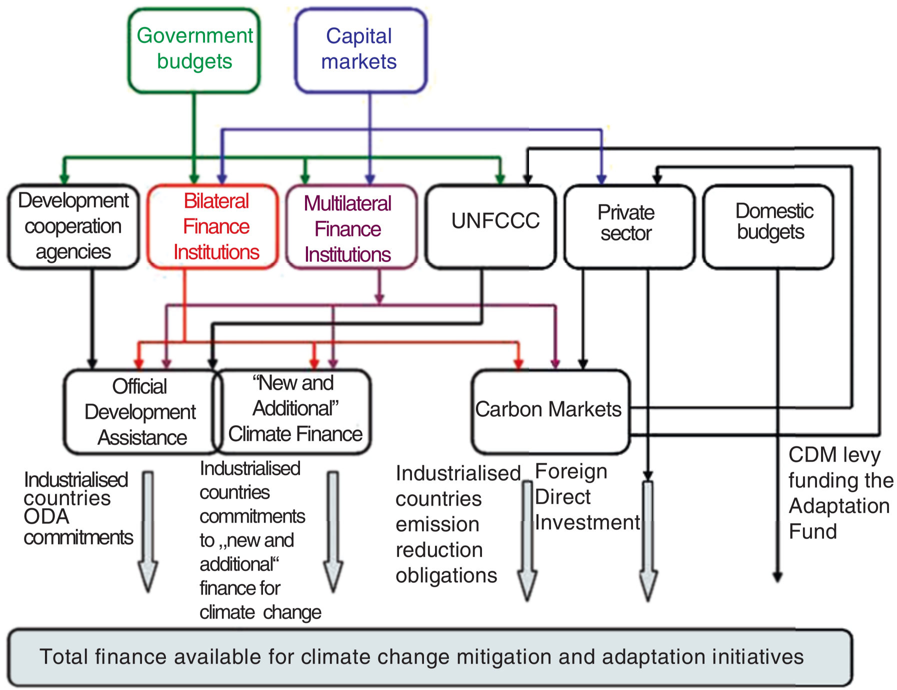

Fig. 6 Financial flows for climate change mitigation and adaptation in developing countries. (Adopted from Atteridge, A., C. Kehler Siebert, R.J.T. Klein, C. Butler, P. Tella – Bilateral Finance Institutions and Climate Change: A Mapping of Climate Portfolios)

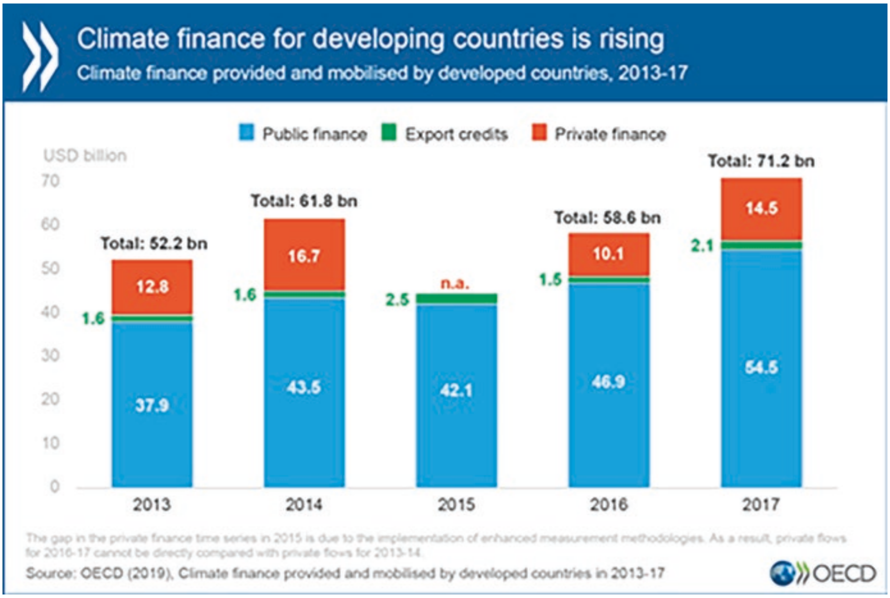

Fig. 7 Climate finance provided by developed countries for years 2013–2017

5 Climate Finance in Developing Nations

The mobilization of capital in developing countries for climate finance lagged far behind the developed world. According to estimates by OECD countries in 2017, developing nations were able to mobilize $71 billion, up from $56 billion in 2016. The developing nations were expected to raise $100 billion by 2020; however, with renewed awareness in the wake of Covid-19, these estimates are very likely to go higher (Fig. 7).

6 Newer Transformative Approach to Climate Finance

World Bank in its recent studies has identified eight drivers. Moreover, the report pinpoints eight ways to drive climate action: project-based investments, financial sector reform, fiscal policy, sectoral policies, trade policy, innovation and technology transfer, carbon markets, and climate intelligence (World Bank 2018). The report further points out how the allocative efficiency can be improved by restructuring disbursements aimed at removing the barriers to implementation of each lever. The application of newer approach is fundamentally a paradigm shift from less efficient to more efficient approach.

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Part II
Policy Measures for Adaptation: Social Security

Need of Social Security in Vulnerable Countries: A Comparison of a Developed and a Developing Country

Aneela Afzal, Tefide Kızıldeniz, Asif Sardar, and Sidra Javed

Abstract Social security systems provide financial support to vulnerable people in times of hardship to fulfil their daily needs. Any changes in social security policies might have a significant effect on mental health, poverty, employment, and education attainment. To examine the impact of the social security systems' transformation, we have reviewed the existing literature belonging to the upper-middle and lower-middle income countries such as Turkey (a developed country) and Pakistan (a developing country) to get important insights. In addition to this, we have also examined the social security systems in the context of the historical transformation to the current era and their effect on the people. Based on the findings, this study found that Turkey has a more comprehensive social security system than Pakistan, which transformed from Ottoman Empire. In Turkey, the frequency of the benefiters has increased from 39% (1975) to 87% (2017), and the budgetary share from 3% (2006) to 5% (2017) for social security institutions. The government of Pakistan has launched some new schemes under the social security systems such as Ehsaas programs, Kamyab jawan program, Koi bhooka na soye, Kisaan card, and Health card to provide help to vulnerable people. Even Pakistan is still far behind in numbers than Turkey. Findings suggest that multiple security schemes work as a tool for controlling labour supply, to help the needy people in the crisis period, mitigating the disastrous impacts to improve the welfare of the people. Pakistani government should pledge more resources and build more institutional infrastructure to improve the social security systems. The government of both countries should focus

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_10

to redistribute the resources from welfare people to the vulnerable and the poor people. And policies should be designed as an alternative solution in the investment portfolio with the social security reforms to reduce inequality among the vulnerable people.

Keywords Social security systems · Schemes · Vulnerability · Welfare · Pakistan · Turkey

1 Social Security Systems Implications in Pakistan

1.1 Social Security in Pakistan: Background and History

Social security is defined as the protection of the society members in case of any risk. Social security ensures health care access to individuals, income security, guaranteed employment, financial aid during work injury, maternity, and loss of bread earner. Social security includes the programs and statutory schemes that are administered and monitored by the government (Niesten 2021). These schemes are programs that cover mainly two domains including social tax financial benefits and social insurance. The tax benefits are usually provided to needy persons based on the vulnerability criteria. While social insurance is usually financed through the contribution of the employees and employers, the benefits are provided to the needed person (Hujo et al. 2017).

Social security is defined by the United Nations (UN) convention and International Labor Organization (ILO) convention as a basic right of the human. However, very few populations of the world enjoy those rights. Pensions are based on contributions to social security to protect health and employment. Social security is limited to only 20% of the world population, while more than half of the population remains neglected (Welti 2018). Most of the old-age people lack the benefits of social security and are unable to pay for health care. According to the International Labor Organization report (2018), people prefer social security, and they are willing to contribute to it as well.

Pakistan is included in the list of some developing countries that consider social security as a principal human right by launching many schemes and programs. The Article 38 (a) (d) & (e) of Pakistan constitution 1973 stated that, *"The State shall provide for all persons employed in the service of Pakistan or otherwise, social security by compulsory social insurance or other means; provide necessities of life such as food, clothing, housing, education, and medical relief, for all such citizens, irrespective of sex, creed, caste, or race, as are permanently or temporarily unable to earn their livelihood on account of infirmity, sickness, or unemployment; reduce disparity in the income and earnings of individuals"* (*The Constitution of Pakistan* 2018).

The social security practices are globally in line with the Sustainable Development Goal (SDG) target 1.3. This goal deals with the universal social security practice implementation and initiation of the program that covers the SDGs in the country (Khan et al. 2016; ShuHong al. 2017).

1.2 Methodology

In this study, we have reviewed secondary published data from different reliable sources related to the social security systems of Pakistan and Turkey. We comparatively analyzed to create inferences between them. For collecting robust information, the authors have made a desk review of the relevant reports and the documents, projects, papers, and web-based publications related to the social security systems and their impact on the society of both countries. Based on the findings of the reviews, impacts and the potential of the relevant stakeholder were explored. In addition to this, we also found the role of the social security systems in the historical context. At the end of the chapter, the authors suggested policy implications that are important for various stakeholders.

1.3 Social Security Systems in Pakistan

Social security schemes of Pakistan deal with the formal and informal sectors separately. The formal sector includes the labourers and retired employees and ensures the protection of the people during sickness, maternity, invalidity, old age sickness, and injury during work. The informal sector of the economy deals with the poor person outside the labor market.

1.3.1 Formal Social Security Schemes in Pakistan

The first social security scheme in Pakistan was the Provincial Employees Social Security Scheme (PSSS), which was introduced in March 1967. This scheme was launched for the textile industry workers to provide them with benefits against maternity, sickness, injury, or death. Many other sectors were also added to this scheme in 1967, related to industries and the commercial sector having more than ten workers. In 1970, this scheme covered the provincial level sectors as well. The Employees Old-Age Benefits Institution (EOBI) scheme was introduced in 1976, and the basic purpose was to provide support to elderly people after retirement. This scheme provides benefits in the form of pensions and old-age benefits. The scheme was financed by the employees, but initially, the employees' contribution was not significant. However, in June 1997, more than 37,000 workers were added to this scheme, bringing the total beneficiaries to approximately 1.2 million workers. The Government Servants Pension Scheme was initiated in 1954 and covers all government servants who have served more than 25 years in any government institution. The government financed this scheme, and workers contributed 8% of their income to it. This scheme provides the Provident Fund and old-age pension to eligible candidates (International Labour Organization 2021; Mahnaz Hassan 2015). The Public Sector Benevolent Funds and Group Insurance Scheme were commenced in 1969. The Benevolent Fund is deducted at source from the monthly salary of the employee's group insurance that is sustained by the monthly contributions of the employees. It covers all public sectors of Pakistan, and in 1993, a total of 19,242 families benefited through this scheme. This scheme covers the Group Insurance, Benefit Grants, and Benevolent Fund.

The Workers Children's Education Ordinance scheme was initiated in 1972. Workers in any sector can contribute to this fund. The worker contributes 100 rupees from their salary to this scheme. The purpose of the scheme is to provide free education to eligible children and help with the vocational training of the students.

1.3.2 Informal Social Security Schemes in Pakistan

The informal welfare system includes three major forms. First, sadqa (which is a voluntary charitable offering in Muslim usage) and zakat (which is an obligatory form of charity that Muslims must give to vulnerable people) are significant provisions that are widely practiced in Pakistan. Secondly, family support is provided to the neediest person in the family. The third form comprises the help of anyone through state resources in the form of job provision, help on the license, and land acquisition resources. According to the report, charity contributes 1.25% of Pakistan's gross domestic product (GDP) (Mahnaz Hassan 2015).

The informal scheme provides cash to the beneficiaries in case of any emergency for the most vulnerable people. Many institutes are working in the informal sector, like Pakistan Baitul-Mall. This institute assists almost every needy person. The Benazir Income Support Program (BISP) is like this scheme. This program was launched in 2008, with the main target being women who had suffered from a natural disaster or lived in a vulnerable area. The climatic change of Pakistan brings a major change to the weather of Pakistan that leads to major climatic shocks like flooding and lower crop yields due to the shifting in the temperature of the area. Agriculture is a major sector of the Pakistani economy, and women majorly contribute to this sector. The outmigration of the male members from villages makes women more exposed to calamities imposed by climate change (Farooq et al. 2020).

1.4 The Current Portfolio of Social Security in Pakistan

The constitution of Pakistan guarantees the prevalence of social security for all without any discrimination. The long-standing schemes that come under social security are the Zakat, Pakistan Baitul-Mal, and Ushr Programmes; the Workers' Welfare Fund; and provincial Employees' Social Security Institutions. The main purpose of the government in Pakistan is to lift people out of poverty and to provide better health facilities while tackling the climate change impacts. Studies (Sardar et al. 2019, 2021) show it is not possible to reduce poverty without sustainable development. It is noted that the Benazir Income Support Programme is a landmark initiative concerning social security to ensure the implementation of sustainable development goals.

1.4.1 Ehsaas Program

The government of Pakistan established the Ehsaas program in 2019. This program focuses on the informal social security systems in Pakistan. Many other programs like the Kamyab Jawan program, koi bhooka na soye, Ehsaas Kafaalat Program, Tahafuz women's centers, and interest-free loans for graduate students. Punjab, Khyber Pakhtunkhwa, and Sindh provinces devised new policies for social security in 2018 and 2019 (International Labour Report 2018). Panagah (an Urdu word meaning "the shelter home") is serving the marginalized people of society by providing them with transitory convenience with multiple meals. This facility benefits meritorious individuals who come to metropolitan urban communities like Islamabad and Rawalpindi in search of education, jobs, or work, as well as people who come for medical assistance or visit hospitals. A person can stay in the shelter for 3 days, which is extendable for one more week depending on the need and condition of the recipient (Panahgah 2021). The key aspect of the program was to give a directed, rule-based, and checked "pannah" to jobless and homeless individuals hailing from various regions. The main purpose was to give instant help to deserving and needy individuals by providing them with fundamental necessities and good quality food. It will likewise assist them with minimizing the severe impact of climate change and decreasing the vulnerability of poor people (Panahgah 2021).

1.4.2 Koi Bhooka Na Soye (No One Should Sleep Hungry)

The Punjab government initially started this program in Islamabad, but now other metropolitan cities are also becoming beneficiaries of this program, like Lahore, Peshawar, and Faislabad. Free meal boxes were served to the daily wage workers under the Ehsas program (Mian 2020). Koi Bhoka Naa Soye program (an Urdu word meaning "No one should sleep hungry") is a step in Pakistan's metamorphosis into a welfare state. Poverty alleviation is the main agenda of the government, and these programs are helping to uplift the people. "Koi bhoka na soya program" was established as a result of private and public partnerships (Ehsaas scheme program 2020).

1.4.3 Kamyab Jawan Program (Successful Youth Program)

The Kamyab Jawan Program (an Urdu word meaning "a successful youth program") is designed to enable the youth to be the most valuable resource/asset of Pakistan. Every Pakistani national, mature person between the ages of 21 and 45 with pioneering potential is eligible to apply for the credit/loan (Mian 2020). There are categories for the beneficiaries, which are divided into three tiers. The purpose of Kamyab Jawan Program is to build institutional cooperative energies and joint efforts to advance gender balance, freedom-based youth strengthening, and institutional improvement (Kamyab Jawan Program 2019).

1.4.4 Sehat Sahulat Program (Health Insurance Program)

Sehat Sahulat Program (SSP) (an Urdu word meaning "health insurance program") is a significant achievement in medical assistance, ensuring that citizens of Pakistan will be entitled to free healthcare from admission to specified medical services. The SSP goal is to further develop the access of the helpless people of society to get great quality of clinical benefits through microlevel medical coverage. There are two main treatment packages: secondary treatment and priority treatment. The treatment includes maternity care, fractures, injuries, diabetes care, prosthetic limbs, dialysis, organ failure, and neurological surgical procedures. Up till now, 7,890,000 families are enrolled or registered, and the satisfaction rate is 97%. The program is being carried out through insurance agencies providing them with free health care through public and private hospitals (Hasan et al. 2018).

1.4.5 Kisan Card (Farmer Card)

Agriculture is considered the backbone of the economy of Pakistan. However, in the last few decades, the population explosion and climate change have badly damaged the agriculture sector. Farmers couldn't attain maximum profit as they lacked access to recent technologies and scientific procedures. Recently, the government imitated the Kisan Card for farmers. This scheme covers farmers all over the country. Kisan Card provides farmers with financial assistance by subsidizing pesticides, herbicides, and certified seeds. This scheme also supports the farmer during natural calamities as well (Saqib et al. 2018).

1.5 Impact of Social Security Portfolio on the Society

1.5.1 Statistics of the Benefiters

The cost of basic needs method is used to measure the poverty condition of Pakistan, and it is reported that 24.3% of the total population lives below the poverty line. To tackle poverty, the government of Pakistan is committed to implement sustainable goal development (SDGs). According to the SDGs, the government could solve the issue of poverty for at least half of the population by 2030. The social security scheme's structure should also in accordance with the SDGs. Ehsaas program and Benazir Income Support Programme (BISP) is the major social security program that ensures the social protection of the vulnerable members of society (Asad 2019; International Labour Organization 2021). Currently, the government of Pakistan allocated the RS 260 billion budget for the EHSAAS program, which was increased from RS 210 billion. This program covers 12 million households, which are more

Table 1 Beneficiaries and their annual expenditures distribution according to institution per program

Institution	Program	Beneficiaries	Annual expenditures (PKR-million)
Benazir Income Support Programme	Waseela-e-Taleem	1,863,549	5600
	Unconditional Cash Transfer	5,783,389	115,000
Pakistan Bait-ul-Maal	Sweet Homes	3145	272
	Child Support Programme	31,438	148
	Vocational Training Centres	157	182
	Great Homes	61	19
	Range of benefits	–	360
Employees Old Age Benefits Institution	Old Age Grant	2231	71
	Survivors' Pension	148,829	6327
	Old Age Pension	248,740	11,279
	Range of grants	649,000	13,875
Ehsaas	Ehsaas Kafaalat Program	6,296,114	206,000
	Ehsaas Emergency Cash	12,000,000	203
	Ehsaas Koye Bhooka Na Soye: Meals-on-Wheels Initiative	17,000,000	26.5
	Kamyab jawan program	4,500,000	1,630,000

Source: International Labour Organization (2021)

than 40% population. Out of the total budget of 150 million allocated for the Benazir Income Support Programme (BISP) (Table 1).

1.6 Impact of Social Security Schemes on Poverty Alleviation

The social protection system of Pakistan majorly focuses on the practices for poverty alleviation. Many schemes were introduced to ensure the social security of the people. Currently, Ehsaas scheme is working for poverty alleviation. This scheme was introduced on March 27, 2019, and the main aim is to invest in people, minimize inequality, and lift the lagging districts. The scheme works for widows, homeless, orphans, disabled, and extremely poor people, poor farmers, undernourished and sick, lower background students, poor women, and older people (International Labour Report 2018). The Ehsaas scheme is aligned with the Sustainable Development Agenda 2030. Most of the achievements and goals of the social security scheme are included in approximately all goals of the SDGs such as SDG 1 (alleviation of poverty through implementing the appropriate social security system nationally and including the vulnerable and poor's), SDGs 2 (eliminating hunger), SDG 3 (healthy well-being), and SDG 4 (good quality education facility) (Asad 2019). Most of the schemes for social security working in Pakistan fulfil the SDG's goal requirement. However, the implementation of these schemes is not effective (International Labour Organization 2021).

1.6.1 Social Security Schemes and Women Empowerment

Women empowerment is considered a potential element toward the poverty alleviation and development of an economic structure for good governance. Women empowerment through social security programs could help to cure the issues of child mortality and income prosperity. In Pakistan, patriarchy is at its peak where women face discrimination in every field of life. The dependence on males for each thing makes the women poorer and weak. Women could play a very positive role in the reduction of poverty (Naseer et al. 2021). BISP has taken the initiative to the work for the empowerment of women in 2008 and tries to protect the poorer segment of the society, which suffers from any natural calamity or inflation through financial support. This program becomes a very popular and biggest program covering 5.29 million beneficiaries. This program covers the health, livelihood, and education issues and tries to remove the financial constraint. Currently, the Ehsaas program initiated the Ehsaas kufalat program (an Urdu word meaning Ehsaas sponsorship program), especially for the vulnerable people. The women were also included in this scheme. The government under this scheme provides 2000 RS per cash to women on monthly basis especially old age women (Multi-Sectoral and Multi-Stakeholder Ehsaas Strategy 2019).

1.6.2 Social Security Programs for Senior Citizens of Pakistan

According to the UN report, the older aged people are increasing day by day, and it is reported that the rate of increment is greater in developing countries. The older citizens of developing countries face major challenges in terms of social benefits. As of 2019, the senior citizen of Pakistan aged above 60 comprise 7% of the total population (Ashiq and Asad 2017). Previously the older people in Pakistan lived in a joint family system and were protected through the next generation, but now this scenario changes rapidly. Fifty-eight percent of the older people in Pakistan live separately. Thus, the support provided by the family member to the elder member of the family is declining. The formal sector of the society receives the pension and other funds through the government if they serve the government according to the requirement of the government. However, informal workers and poor old citizens face many hurdles in this situation. Government initiates social security schemes for elder citizens like Baluchistan Senior Citizen Act (initiated in 2017 by Baluchistan Provincial Assembly), Sindh Senior Citizen Welfare Act (initiated in 2017 by the Sindh government), and Khyber Pakhtunkhwa Senior Citizens Welfare Act (initiated in 2014 by the Khyber Pakhtunkhwa government) (Irudaya Rajan 2014). The major purpose of these schemes is to support the elders in terms of medical facilities and wellbeing (Ehsaas scheme program 2020).

1.6.3 Social Security Schemes in Wake of the Crisis

Social security also deals with natural calamities. Pakistan relies on natural resources and has an agrarian base, so climatic shift brings many disasters. Pakistan faces frequent flooding, drought, earthquake, glacier retreat, and water resource depletion due to the climatic shift. The impact of these natural calamities is drastic for the livelihood of the farmers of Pakistan. Agriculture sectors face many issues due to climate shifts. The families of the farmers especially women and children suffer more than the other members of the families. A rural woman in Pakistan has responsibility for household chores as well as farm-related tasks. The Pakistan government tries to provide support to people who suffer from natural calamities (Khan et al. 2016). For instance, the UNICEF program disaster risk management focuses on the capacity building of vulnerable citizens to deal with disasters. The Pakistani government also supported the weaker citizens of the society during the outbreak of COVID-19. It is reported that COVID-19 exacerbates poverty in Pakistan (Farooq et al. 2020). At the federal level, Ehsaas Emergency Cash Transfer Programme was initiated by the government to support the people who were severely affected by the pandemic and the climate disasters.

1.7 Implication

The social security system of Pakistan is in line with the SDGs, but to fulfil these goals, the government must improve the policy structure. Rather than the poverty-targeted paradigm, the policies for social security must be people-focused and follow the rights-based approach. The government designs social security schemes in accordance with the ILO Social Security Convention, No. 102 (International Labour Report 2018). Most of the programs are not implemented due to hindrances in terms of communication and lack of awareness. The government must establish a non-technological, community-facing, and alternative solution for communication. The government should develop a policy framework that outlines the role of the federal and provincial governments in designing and implementing the policies (Pakistan Overview: Development News 2021).

2 Social Security Systems Implications in Turkey

2.1 Social Security in Turkey: Background and History

Social security has significant importance in strengthening the cultural, social, and economic development of the country. The welfare and income of the people are the main indicators that are used to measure the development and the progress of society. In addition to this, it is one of the main components of the antipoverty strategy and social risk management strategy, removing equality and redistribution of income to expand the social welfare of the people. The social security system improves income distribution among the poor people living in marginalized areas to build a peaceful society. The social security system has transformed from the Ottoman Empire to the Republic of Turkey in different ways. As a result, an eye view of the Ottoman Empire is required to obtain valuable linkages between the social and cultural effects on society in order to understand the history of Turkey's social security system.

2.1.1 History of the Ottoman Empire

The Turks have a history of establishing the Ottoman Empire and constructing measures for the welfare of the people. The Ottoman Empire was founded at the end of the thirteenth century in north-western Anatolia. It remained in power till the twentieth century before the first world war. This Empire contained a large land area with a diversity of land, geography, and culture. They have taken several steps to improve the welfare of the people (Nisancioglu 2014). Turks were left behind during the independence war and World War I. But they fought for their country against the allied forces and emerged as the Republic of Turkey in 1923.

2.1.2 History of the Republic of Turkey

Modern Turkey came into being in 1923. Since then, the government has given significant attention to the welfare of the people. The Turkish government has passed a bill to protect the rights of the people in the line of social security (Turnaoğlu 2017). According to Turkish law (Article No. 60), *"Every person who is a citizen of the Republic of Turkey has the right to get social security. The state is responsible for putting in place all necessary measures and drafting a constitution to ensure social security"* (Ince and Akyüz 2018).

The Turkish government has established Social Insurance Institute in 1965 under Act No: 506. In the Turkish language, this Social Insurance Institute is called Sosyal Sigortalar Kurumu (SSK). The social security system in Turkey is administered by the government-owned social security institutions (SGK) (Altunkaynak 2018). It works in two ways. One is contributory components, which are called social insurance, and the other is noncontributory components. Later deals with social services and social assistance for vulnerable people. Social security coverage is divided into two main types based on their time duration. One is short term and the other is long term. Short-term insurance covers the areas of occupational diseases, accidental death, maternity, and health-related issues. While long-term insurance covers death or survivorship and old age-related issues. Government makes the social security system compulsory. The funds for the social security system are generated by contributions from the state, employees, and employers. The amount is calculated based on the earnings up to a ceiling. The Turkish government has exempted vulnerable people from contributing to the social security fund. They are referred to as noncontributory components. They might belong to the group of needy people, elderly

Table 2 Year-wise details of the establishment of the Social Security System or Social Security Rights

Social security system (retirement funds) for obtaining social security rights	Year of establishment
General women	1593 and 1978
Retirement of employees	1866
Asakir-i Berriye	1880
İdare-i Mahsusa (Seyr-i sefain)	1890
Şirket-i Hayriye	1893
İlmiye	1894
Rümusat Kantarcıları and Muhafaza Kayıkçıları	1896
Hamidiye Hejaz Railway Civil Servants	1904
Private workers	1946
The Public who are self-employed	1971
The Public who are engaged in the agriculture sector	1983
Civil servants	1909
Artists	1978
Convicts (only for those woes arrested due to occupational accidence etc.)	2004
Jockey and Trainer	2008

Source: Özdemir (2021), Orhan (2016), Doğan (2020)

people in need or disabled persons, people who fall below the poverty line, people who cannot bear their medical expenses, orphans or widows in need, children that need protection, and people who are vulnerable due to climatic disasters or weather variability. The Turkish government has awarded noncontributory people green cards. This card is given only to those who are very poor or unable to survive or belong to the poorest family under section Article No. 60.

2.1.3 The Overall History of the Establishment of Social Security Funds, Rights, and the Institutes in the Ottoman Empire and Modern Turkey

Some details about the history of the development of the social security system in the Ottoman Empire and the Republic of Turkey to raise the welfare of the people are given in Table 2.

2.2 The Current Portfolio of the Social Security System

2.2.1 Social Security Coverages

The Turkish government extended the Turkish social security system to all public, private, and self-employed employees in 2006. Over time, the Turkish government has brought more and more people under the umbrella of social security. The

Table 3 Information about the persons who are included in social security coverages

Category	Years		
	1975	2010	2017
Population (thousand)	40,347	73,722	80,810
Social Security Coverage (sum of all four types stated in the above literature)	16,037	61,526	70,463

Source: Orhan (2016)

Turkish government has provided social security in terms of four categories: (1) insured persons, (2) dependents, (3) funds to the vulnerable people, and (4) pensioners (The Republic of Turkey, Ministry of Labour and Social Security, The European Code of Social Security 2021). The percentage of the population covered by social security increased over time, from 39% in 1975 to 68% in 2005 and 87% in 2017. Detailed information about the social security coverage is given in Table 3.

2.2.2 Budgetary Share of the Government Spending to the Social Security System

The Turkish government has raised its budgetary share of social security in the GDP over time. The share of social security in the GDP was 3.02% in 2006, 3.78% in 2014, and around 5% in 2017. But it is necessary to mention that this social security rate is still far below the European states, which are called social states (Aysan 2020; Baylan 2019). Social security law protects the peoples' rights and helps to provide a better quality of social security services to the whole population with easy access irrespective of the status of the people (Tümer et al. 2011).

2.3 Impacts of the Social Security Schemes on the Society

2.3.1 Statistics of the Benefiters

Turkish national and subnational governments are currently running many programs under different heads of the social security system under Turkish law. Details about the number of persons who have received benefits from social security programs are given in Table 4.

2.3.2 Impacts on the Labour Supply

Literature suggests that social security improves the incentives for government and private employees and increases the savings of the labor due to the rise in labour supply. So, it raises the standard of the poor people living in the

Table 4 Social security types and the beneficiaries

Social security types	Total beneficiaries
Personal type	81.92%
Material type	–
Medical type	64,736,434 (persons)
Sickness benefiters due to occupational Accident type	2,716,028 (persons)
Unemployment benefiters	13,276,604 (persons)
Old age benefiters	6,191,643 (persons)
Family benefiters	------
Maternity benefiters	------
Survivors' benefiters	3,142,384 (persons)

Source: The Republic of Turkey, Social Security Report (2015)
[a]Official figures were not found

marginalized areas and also supports the elder population, which would cause a rise in the size of the economy. Therefore, social security plans and their modifications over time increase the earnings of the people. So, the literature suggests that it has the potential to encourage labour supply. This would increase the government's ability to save and contribute more to the government's reserves. Social security systems can also be used as a tool for the policy of supply chain management. So, it is suggested that social security reforms can be an important instrument to expand the incentives for controlling the labour supply in the country. Nonetheless, this system can be used to improve the well-being of a specific group of people in order to reduce vulnerability and poverty among the marginalized (Elveren 2008).

2.3.3 Impact of Social Security in the Crises Period

Literature suggests that during the crisis period such as the coronavirus period or any natural disastrous situation, the immediate effect of the social security system in the crisis period was observed that the claims for the unemployment benefit increased. The social security administration managed the crisis time through the active portfolio of the funds by using reallocation of the investment. Many people who fell below the poverty line due to the crises were called the new poor. And people demand more housing and social assistance benefits. These institutes assist the people who are the victims of the crises time and are vulnerable by giving cash transfers and providing goods to the people (Aydede 2011). To reduce the degree of uncertainty, it is suggested that the government stimulate assistance packages to improve the social structure for the vulnerable, particularly those living in marginalized areas. In this regard, social policy interventions are required through alternative solutions in the investment portfolio and by removing barriers to affected people's communication in the face of exceptional challenges.

2.3.4 Distributional Impacts of Social Security on the Welfare of the People

The main objective of the social security system is to maintain and fulfil the needs of the vulnerable and the poor people by providing support for their consumption needs and welfare. These institutes are focusing more on the people who have fewer current resources than their future requirements. The distributional effects of social security redistribute income from the young to the elderly, as well as from the wealthy to the vulnerable and poor. But these impacts are based on the social security tax rates. It is evident that the benefits of the social security system are progressive, but the taxes imposed on the people should be regressive in nature (Papps 2012). So, this study suggested that the government should focus on the social security reforms considering the income differenced poor people across-the-board. The tax base should be decreased, which would reduce the inequality and will raise the standard of living among the poor people.

3 Conclusion and Recommendations

This chapter has shown the details of the social security systems that prevail in both countries, that is, Pakistan and Turkey. Social security schemes are very crucial for the welfare of society. Since its formation, Pakistan suffers from the peril of poverty. The Government of Pakistan tries to protect the citizens through propagating social security schemes like BISP, Employees Old-Age Benefits scheme, Government Servants Pension Fund, Workers Welfare Fund, etc. Currently, the Ehsaas program has become the first-ever social security program that provides benefits to every vulnerable group in society. Furthermore, the Ehsaas program is in line with the goal of SDGs. However, the implementation of these programs is not fulfilling the needs of society. Government must shift the social security paradigm from poverty alleviation toward a right-based and people-focused approach. The program must be gender-responsive to overcome the issue of gender disparity. Women are the major victims in any climatic disastrous event even in COVID-19 as well. Many women in Pakistan are illiterate and lack the required attitude toward new technologies like mobile or internet usage. So, the schemes must be designed to remove the barriers in the way of communication, awareness and resource constraints. The hurdles in this way of social security program implementation could be removed by involving the civil society organizations that work for the community mobilization. Similarly, Turkey has developed formal institutions and the infrastructure of the social security system in the country. This system worked from the Ottoman era to the current Republic of Turkey. The social security system in the Turkish community was established in the fifteenth century during the reign of the Ottoman Empire. This system was transformed into the modern Republic of Turkey which was established in 1923 with modern reforms and development in line with Article No. 60 to protect the rights of the people and the welfare of the society. The national government of Turkey has established Social Insurance Institute (Sosyal Sigortalar Kurumu (SSK)), which administers and supervises all local institutions that are working for the social security system in the country. This system works in two broad categories, that is, contributory components and noncontributory components, based on the short-term and long-term objectives. This social security system covers the multiple dimensions of the welfare of the vulnerable people, such as support for elderly people or disabled persons, occupational diseases, accidental death, maternity, financial help for survivorship and for the needy people, or the people who fall below the poverty line or cannot bear their medical expenses, orphans or widows in need, children that need protection, and the affected people due to weather variability for mitigating the risks and impact of the climatic disaster. The Turkish government provides support to the people in terms of cash, luggage, tangible items, etc. Over time, the national government has increased the budgetary share for the social security system, and hence, the frequency of benefiters also rises. This system acts as a tool for controlling labour supply in the market. It also acts as an incentive for employees and helps to increase the savings of the labour. This chapter finds that the welfare of the Turkish people has increased over time. It helps the marginalized people to maintain their daily intake needs. Literature shows that this program remains very helpful to the poor people during crisis periods such as unemployment, lockdown during coronavirus, and migration. This system helps to redistribute the income effects from the young to the older age and from wealthier people to the vulnerable and the poor people. It is suggested that social policy should be designed as an alternative solution in the investment portfolio with the social security reforms. It is necessary to consider the decrease in the tax base for the poor people to trigger the distributional impact. It would help to reduce inequality and raise the standard of living of poor people.

Acknowledgments The authors gratefully acknowledge PSDP funded project No. 321 “Establishment of National Center of Industrial Biotechnology for Pilot Manufacturing of Bioproducts Using Synthetic Biology and Metabolic Engineering Technologies at PMAS-Arid Agriculture University Rawalpindi,” executed through the Higher Education Commission Islamabad, Pakistan. This study is a part of the above mentioned project.

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Climate and Development

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Abstract Climate can be defined as a long-term weather pattern of a region, usually averaged over 30 years. It is the average variability of meteorological variables across time, from months to years. Agriculture, cattle, and fisheries all, which contribute significantly to the overall economy of a country, on the one hand, are dependent on climate but, on the other hand, emit greenhouse gases (GHGs) which are responsible for climate change. Climate variability plays a crucial role in agriculture and fisheries. As a result, warmer conditions and CO_2 levels can have a significant

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_11

influence on basic nutrients, moisture content, and porosity and on many essential performance factors. Globally, climate change is happening because of global warming (GW). Climate change poses a serious risk to the environment, and people are making great efforts to find a better solution. According to a study, the twenty-first century will have a limited impact on human welfare and the economy. Initially, climate change (CC) impacts can positively influence the economy, but with time, negative aspects of climate change will cover the positive ones. Climate change will negatively affect lower-lying, poor, and hotter countries. Various economies globally are working together to slow down environmental degradation and maintain long-term prosperity. To decrease the climate change impacts, we should focus on reducing poverty and GHG emission. While climate change can influence the economic growth rate at a global scale and can cause poverty in many countries, evaluation of these effects will be difficult to assess. Therefore, assessing the impacts of climate change scenarios at more localized levels is an important research goal in this context. Calculating the carbon shadow price in agriculture and cost-benefit analysis of adaption programs is essential. These strategies are required for the development of effective policies which can increase agricultural resilience to climate change in different situations. In vulnerable populations, climate change adaptation and mitigation strategies are essential to protect the human society and their rights and promote justice in society.

Keywords Environmental degradation · Climate change adaptation · Urbanization · Urban floods · Socio-economic impacts

1 Introduction

Climate is known as a long-term weather pattern of a region, usually averaged over 30 years. It is the average variability of meteorological variables across time, from months to years. The emission of greenhouse gases (GHG) is continuously increasing, responsively our climate is changing, and people are adapting to new situations and coping with these circumstances. The unpredictable nature of climate change poses serious threats to the earth, such as increasing poverty, inequality, and growing urbanization problems (Magnan et al. 2020).

Our world is becoming more urbanized and globalized, and the increased discovery of natural resources might destroy environmental quality. Since the beginning of time, many things have changed. The climate is one of them, and it is the most crucial. Environmental preservation and sustainability problems are becoming more popular with each passing day. Various economies globally are working together to slow down environmental degradation and maintain long-term prosperity (Gaillard 2010). Globally, climate change is happening because of global warming (GW).

Climate change poses a serious risk to the environment, and people are making great efforts to find a better solution.

To mitigate or remediate the negative effects and consequences of climate change globally, many frameworks have been adopted such as the Earth Summit of 1992 in Rio de Janeiro, the Kyoto Protocol of 1997 in Japan, the Durban Platform for Enhanced Action of 2011 in South Africa, the Cancun Agreement of 2010 in Mexico, and the more recent Paris Agreement of 2015 in France (Guerrina et al. 2021). In global warming, some gases are continuously contributing, for example, carbon dioxide, nitrous oxide, methane, chlorofluorocarbons, and water vapor. In the overall GHG emission, the contribution of CO_2 is 81%.

According to British Petroleum 2018, the worldwide CO_2 emissions in 2017 were 33,444.0 Mtoe (Guerrina et al. 2021). The active contributors to CO_2 emission are economic expansion, urbanization, natural resource exploitation, and globalization. Internationally, emission of harmful gases is rapidly increasing (Ford et al. 2010). Latin American and Caribbean countries (LACCs) have abundant natural resources, but for reduction of harmful greenhouse gases, these countries must have to revise their frameworks for forestry, agriculture, and other industries. For the reduction of GHGs, long-term strategies are required for sustaining the economy, reducing emission, and preserving the environment. The depletion of natural resources may harm the environment. In the early stages of development, countries utilize more energy (natural resources) and deteriorate the environmental health, but when growth starts, their attention shifts towards renewable resources with more preservation of natural resource, clean energy, and other environmental concerns (Michaelowa and Michaelowa 2007). As a result, the environment's quality becomes better.

Economic growth encourages industrialization, which consequently improves the exploitation of natural resources. Using natural resources like mining, deforestation, and agriculture may degrade the quality of the environment due to increased emissions. Extraction of natural resources destroys biocapacity, resulting in environmental deterioration. People should be skilled and educated for the sustainable use of natural resources, ultimately increasing environmentally friendly and energy-efficient technological advancement (Nathaniel et al. 2021).

2 What Causes Climate Change

According to scientific research, a rise in greenhouse gas (GHG) emissions, primarily carbon dioxide, is linked to more global warming during the last 50 years. GHGs are present in the earth's atmosphere; they trap heat and increase the earth's surface temperature.

- Anthropogenic activities are responsible for the increase of GHGs.
- Fossil fuel burning like oil, coal, and gas releases CO_2 into the atmosphere.

- Trees store carbon inside them; when they burn as an energy source, they release carbon dioxide into the atmosphere, and vegetative land is also affected during the cutting of trees.
- GHGs are released during different agricultural operations. Cattle generates methane gas during stomachic fermentation (which occurs in ruminant animals' digestive tracts), and nitrous oxide is released during the production of numerous fertilizers.
- To empower their economies, countries use fossil fuels and remove forests to make space for habitation and cultivation; these activities have expanded considerably in recent years. The demand for cropland and animal products is increasing in response to the rapidly growing population worldwide. As a result, GHG emissions are anticipated to increase further in the future.

3 Climate Change Effects on Developing Countries

According to a study, the twenty-first century will have a limited impact on human welfare and the economy. Initially, climate change (CC) impacts can positively influence the economy, but with time, negative aspects of climate change will cover the positive ones. Climate change will negatively affect lower-lying, poor, and hotter countries. To decrease the climate change impacts, we should focus on reducing poverty and GHG emission. While climate change can influence the economic growth rate at a global scale and can cause poverty in many countries, evaluation of these effects will be difficult to assess.

Climate change can influence the size of the labor force and capital stock productivity, ultimately affecting investments and future outcomes. Furthermore, climate change will also affect the technological progress, ultimately decreasing economic growth. Unfortunately, climate change's impacts on the development of developing countries are still unclear and need further research (Tol 2018). Poor people and developing countries are more at risk to climate change and the consequences of climate change (CC), for example, natural disasters can destroy livelihood and assets. Furthermore, pests and waterborne diseases become more common during droughts, heat waves, crop failure due to less rainfall, increase in sea levels, floods, and higher food prices between extreme weather events. Today, climate events and climate conditions are causing poverty in many households. In developing countries, environmental problems and climate change also affect the health and education system and cause health shocks (death and illness) in people, more rainfall, high temperature, diarrhea, and malaria. Climate conditions also affect people's mental health and behaviors due to the possibility of risk; they avoid investing in assets and reduce the investments to prevent destructive outcomes, which further leads them to poverty (Hallegatte 2016).

Climate change can increase the threat to existing health problems (Wu et al. 2016). Scientists have indicated that climatic and weather conditions such as violent storms, rainfall, and temperature can affect the performance of economies and the nature of societies (Carleton and Hsiang 2016). Health and environmental outcomes of climate change affect the developing countries and poor people in developed countries as well as social justice and human rights. The negative impacts of climate change have adverse effects on the availability of potable water, lower agriculture production, and workers' productivity by uncultivatable land due to inundation.

Climate change adversely causes waterborne diseases, vector-borne diseases, allergic and respiratory disorders, heat-related disorders, mental health problems, violence, and malnutrition. These health and environmental outcomes threaten political, civil, cultural, economic, and social rights, including the availability of safe drinking water and food, shelter, and health security. In developing countries, older people, women, minority group members, children, disabled people, people with chronic diseases, and workers exposed to weather variability and extreme heat are vulnerable to the harmful consequences of climate change. Globally, developed countries produce more GHGs than developing countries, but developing countries face more adverse effects of climate change due to their lower capability to adapt to climate change (Levy and Patz 2015). Developing countries face more challenges and difficulties in fulfilling the growing demand for water, food, and energy. Effective adaptations are required to minimize climate change's negative consequences by efficiently using vital resources, energy, and water. Some developing countries, especially in South Asia, follow a sectoral approach without considering interdependence and interconnection between sectors (Rasul and Sharma 2016).

4 Development and Environmental Degradation

The literature has given much attention to the relationship between globalization and environmental deterioration, with inconsistent results. From 1970 to 2015, Wang et al. (2020) examined the potential environmental damage that globalization might have caused in a group of seven countries (G7). According to the results, growth and globalization are the main contributors to CO_2 emissions. From 1990 to 2013, Enríquez-de-Salamanca et al. (2017) used the approach of generalized method moment (GMM) to investigate the globalization impacts and economic growth on carbon dioxide emissions in 36 SSA nations.

It is observed that economic development increases CO_2 emissions, in accordance to Saupe et al. (2019) findings, while globalization imposed costs for a greater negative influence on the environment. Urbanization increases the emission of harmful gases, whereas globalization only slightly decreases them, with visible effects on energy and poverty. From 1970 to 2014, Saint Akadiri et al. (2020) investigated economic expansion impacts and globalization on carbon dioxide emissions in Turkey. Electricity consumption and economic expansion deteriorate the environment, yet globalization has no negative effects on the environment.

Similarly, from 1990 to 2016, Wang et al. (2019) investigated the relationship between globalization, financial advancements, and carbon dioxide emissions in Asia Pacific Economic Cooperation (APEC) nations. Human capital has the potential to restore and preserve environmental sustainability. It has been linked to natural resources and has been linked to environmental deterioration in the literature.

However, this research does not consider human capital as a possible factor. The study examined those natural resources that are responsible for the environmental health of BRICS nations. However, economic expansion was the major cause of environmental damage. From 1971 to 2014, Zubaidi et al. (2020) examined the influence of human beings on environmental quality in G7 nations. They observed that human capital, like FDI and export, supports environmental sustainability, whereas import and urbanization do not. The autoregressive distributed lag (ARDL) method was used by Hussain et al. (2020) to examine the connection between China's human capital, environmental quality, and natural resources. According to their results, natural resources deteriorate the environment, whereas human capital enhances it (Rahman et al. 2021). Impact of human actvities and natural resources on the environment in the United States from 1970 to 2015, adjusting for foreign direct investment. They found that the United States' environmental quality is improved by both natural resources and human capital.

Using the ARDL approach, Rahman et al. (2019) investigated the influence of human capital and bio-capacity on environmental deterioration from 1971 to 2014 in Pakistan. They observed that bio-capacity and human capital both contribute to environmental deterioration unexpectedly. Natural resources harm the environment, according to Shittu et al. (2021), which cause a disturbance between the environment and natural resource. Hussain and Dogan (2021) used the AMG approach to evaluate the natural resources and CO_2 emissions between the BRICS countries, finding that natural resources worsen emission of harmful gases in Russia, South Africa, Brazil, and China but did not affect India. Most researchers found that depletion of natural resources and economic expansion harm the ecosystem, but urbanization impacts on the environment are unclear. Variation in findings might be due to estimating technique, the location or country investigated the dataset's nature, etc. In addition, few research works focused on human capital concerning natural resource deterioration and environmental degradation.

5 Climate Change Impacts

Climate change occurred because of significant increase in surface temperatures, humidity, ambient water content, and changes in precipitation patterns. Because a slight change in rainfall variability and mean can generate a considerable increase in extreme rainfall. Extreme rainfall events are expected to become more intense when the climate warms. Warming is also expected to impact urban areas (Yalew et al. 2020). Higher temperatures produced by urban heat islands (UHI) can alter the microclimate of cities, enhance the climatic variability due to global warming (GW), and increase the intensity of rainstorm occurrence in these places. Due to the impacts of rapid urbanization, rainfall intensity and frequency can be higher in city areas. Extreme rainstorms impact paved regions more than unpaved places (Perera et al. 2020). Activities of urban development can decrease the plant cover and create water resistance areas, which lowers the infiltration capability of rainwater on land surface and ultimately increases the surface runoff. Impacts of changes in land use, runoff peak, and volume are often overlooked in the latest design of an urban drainage system, which are utilized for the prevention and regulation of floods. As a result, significant flooding occurs in urban areas during a rainstorm (Pour et al. 2020). Furthermore, newly designed drainage systems are typically based on static climatic data or historical rainfall characteristics evaluated for a certain time, without taking into consideration the variations in rainfall type throughout time.

Globally in many places, climate change increases the volume and intensity of heavy rainfall, consequently increasing the flood frequency and property destruction. Sustainable urban stormwater management has obtained a lot of attention in dealing with the rise in urban flood frequency and intensity (de Lima et al. 2021). Low impact development (LID) buildings are increasingly used for the improvement of water penetration into the subsurface. LID refers to a strategy and methodology for regulating runoff of stormwater and improving infiltration of the system to minimize surface runoff. Rain gardens, maintenance structures, green roofs, and highly porous roadways are one of the LID practices proposed and implemented in managing urban stormwater.

LID approaches have become popular as an alternative to conventional stormwater management strategies. Consequently, these considerations provide us with adequate solutions to promote sustainable city growth and create climate-resilient civilization (Baek et al. 2020). Several research works have documented the effectiveness of low impact development as a technique for the mitigation of urban floods. This research found that different LID techniques provide distinct advantages to runoff and urban ecosystems in different climatic and geographic zones (Peng et al. 2020). LIDs maintain local environmental characteristics, safeguard natural ecosystems, and increase the groundwater levels to mitigate development consequences on local hydrology.

As a result, it decreases the requirement for large-scale rainwater storage pools. Consequently, LID can be a highly good infrastructure investment technique in urban growth. LIDs are often extremely suitable, cost-effective, and climate-resilient for sustainable urban projects (Pour et al. 2020). Zhan and Chui (2016) managed the analysis of cost-benefit practices of LIDs in Hong Kong and found the US$5.3 billion economic gains and US$1.2 billion environmental benefits over 30 years. LIDs also reduce flood damage to structures. Evidence showed that LIDs reduce damage to buildings caused by the sandy hurricane in New York City in 2012. However, still useful information is not available to understand how different forms of LIDs might be used to manage urban flooding, how climate change can be addressed through LIDs and influence the variability in extreme rainfall, and which problems are present there while implementing LIDs for urban flood mitigation strategies (Yang et al. 2021).

6 Urbanization and Climate Change

The proportion of people living in cities has risen from less than 30% in 1950 to almost 55%, indicating the growing global urbanization. From 1992 to 2016, globally urbanized land area was around 346.4 thousand km^2 (Li et al. 2020). Worldwide, urbanization has grown from 0.6 m km^2 to 0.9 m km^2 between 2000 and 2010. Although areas of metropolitan cities only account for 3.6% of the whole earth's land surface, this urbanization increase contributes to ongoing environmental challenges such as biodiversity loss, increase in pollution, and hydrometeorological disasters, especially floods in urban areas. Globally, impacts of floods are extensive; they cause damage to both humans and the economy of countries, and it will increase when the growth rate of the population grows (Qiu et al. 2020).

7 Urban Floods and Climate Change

Flash floods, riverine floods, tidal floods, and other types can be classified according to their features. A flash flood happens when a lot of water collects in a small area after a heavy rainstorm, especially in a region with steep terrain. The water then swiftly flows downslope. These significant rainfall occurrences frequently have an impact on towns and cities that are situated in valleys or on the lower slopes of hillsides. A flash flood's geographical coverage and duration are often shorter than a regular flood event. Still, the damage caused by the quick appearance and speedy movement of a huge water volume can be significant (Verrest et al. 2020). Precipitation that falls over a broad region over a long period, on the other hand, can cause riverine flooding. Riverine floods, which occur across a vast region and for a long period in cities next to huge rivers, are common. The floods in European towns exemplify riverine flooding due to the Danube River overflowing after particularly heavy rain (Pour et al. 2020). Tidal floods caused by cyclones and storm surges may potentially impact coastal cities. High waves often carry a massive amount of energy and can be destructive. The inundation level of tidal flood could be quite high, and it varies between tidal motions. On October 17, 2016, in Miami Metropolitan Area, tidal flooding swamped a large area, with floodwaters up to 3 m deep. Urban floods are a special type of flood that occur when the city's drainage system fails (Singh et al. 2020). Due to low availability of land for water depletion and infiltration, majority of city rainfall will have to be drained by using current drainage systems of rainfall which are designed to manage less runoff water. Floods can occur when the total volume of water and amount of precipitation exceeds the drainage capacity of the system. Rainwater starts to accumulate outside of the drainage system, causing water to stagnate in lower areas (Xu et al. 2020). Floods in metropolitan areas restrict highways, inundate homes in lower regions, and disturb the lifestyle of people. Because of higher human density, economic activities, economic losses, expensive valuable properties, and structural damage to property can be crucial (Wu et al. 2020).

8 Cities and Climate Change

Changes in land use and microclimate occur because of urbanization. Urbanization and global warming affect an urban region's local climate and change it to a significant extent as compared to the climate of a nonurbanized area. The urban climate frequently increases natural variability caused by large-scale weather phenomena, which might affect the intensity of these occurrences. According to various studies, urbanization can change rainfall patterns, humidity levels, wind speed, and direction. Rainfall can be higher and more severe during the rainy months/wet seasons. Beijing, a massive city, experienced an increase in the frequency of severe rainstorms over the summer. According to 48 research studies on the influence of urbanization on rainfall, the mean precipitation increased by 218% within 20–50 km in between city centers (Wu et al. 2020).

9 Climate Change Impacts on Urban Floods

The PMF is calculated using the highest rainfall that may occur at a given place within a specific time, such as a 1-h rainfall. The highest rainfall in significant catchment circumstances (such as extreme moisture content) is used to calculate the PMF. When urban hydraulic systems cannot be modified and upgraded with the necessary improvements in design to coincide with recalculated PMF, it can increase the risk of urban flooding. According to research, metropolitan areas might increase flood peaks linked with return times. Climate change can cause changes in land use and may cause flooding because of increase in rainfall events and urbanization. The proportional impacts can be determined by the level of urban development sustainability (Scoullos et al. 2020). In unsustainable cities, the major contributors are urbanization to flood peaks and the frequency of floods. According to the findings, future urban floods might be far worse. Many cities are expected to face significant increases in flood danger (de Almeida et al. 2018). The inherent uncertainty associated with flood estimates is the biggest challenge in decreasing urban flood risk. A rise in urban floods in those areas posed a serious risk and significant challenge for decision-makers while planning urban stormwater management systems (Wu et al. 2021).

10 Climate Change and the Environment

“Climate” refers to a worldwide climatic scenario that may be detected in the atmosphere through temperature, precipitation, pressure, and humidity changes. The word “climate change” refers to an environmental change because of natural or human activities. Climate change is causing global warming, glaciers melting, unpredictable weather patterns, rising sea levels, and other global climatic occurrences. Several experts, professors, environmentalists, and members of the general public feel that natural destructions, for example, hurricanes Maria, Irma, and Harvey, demonstrate the climate change effects (Ahmad et al. 2020). The ever-increasing outcomes of climate change need immediate actions towards phenomena, and communities are obligated to engage in adaptation initiatives of climate change. GHG emissions are the main reason to climate change, as these gases are abundant in nature and greatly impact the climate. Climate change was "underestimated" due to a slow increase in unfavorable atmospheric occurrences worldwide (Gopalakrishnan et al. 2020). In addition to human activities, natural activities such as volcanic eruptions, earthquakes, and solar cycles have an important role in environmental deterioration. Naturally occurring sinks have previously maintained the emission of GHG below dangerous levels; however, ongoing human interferences, such as automobile usage, forestry, and agricultural activities, have increased GHG emissions (Yoro and Daramola 2020). Apart from H_2O vaporization, global emission of GH gases is rapidly growing. The growing global warming phenomenon due to emission of GHG deteriorated the natural environment and unbalanced the climate (Zhao et al. 2020).

The two main causes of anthropogenic carbon emissions in the atmosphere are human-caused fossil fuel consumption and changes in land use, which have contributed to global warming (GW) from the midtwentieth century. The Septembers of 2018–2017 experienced the fourth highest temperatures in the previous 139 years, and on 2013, ten warm summers and five warmest Septembers ever were observed. Variations in atmospheric circulation, environmental destruction, economic losses, social degradation, and continuously rising temperatures pose a risk to humans (Mikhaylov et al. 2020).

Climate change has harmful impacts on human activities, particularly on agricultural and farming practices in Asia, due to GH gas emission and the influence of greenhouse gases. Pakistan's geography makes it sensitive to the consequences of global warming. Many Asian countries face sustainable and ecological development hurdles due to the scarcity of industrialization, urbanization, and economic progress. Globally, agricultural and financial progress activities contribute to the degradation of biodegradable and nonrenewable resources (Tingbani et al. 2020).

The negative consequences of this severe exploit have a long-term and negative influence on the environment. Implementing policies incorporating environmental awareness, community involvement, historical obstacles, behavioral intents, and respect for Mother Nature should be among the climate change mitigation approaches and reducing the impacts of natural deterioration. In 2010, global GHG emissions increased by 5.8%, which was higher over time. Due to the harmful effects of climate change, Pakistan's financial, social, and environmental growth can be endangered.

By 2030, an increase in urbanization, transportation, energy consumption, and trash is expected to increase the global ranking. Climate change rapidly impacts Pakistan, with the severity of events like the melting of glaciers in the Himalayan range at a higher rate never seen before (Kuvadia et al. 2020). Unpredictable floods, droughts, fluctuating temperatures, a scarcity of water supplies, human health problems, pest illnesses, seasonal changes, and lifestyle changes all contribute to destruction. Extreme heat, water inundation, cyclones, thunderstorms, volcanoes, and disasters are all-natural disasters. Because climate change impacts are visible, the mandatory steps and actions are necessary for mitigation, including prevention from future GHG emissions and lowering the present level of GHGs from the atmosphere, and adaptations that include adjustment in changing climatic impacts (Tingbani et al. 2020).

11 Socioeconomic Impacts of Climate Change

Climate change is producing social and political disturbance, as well as global migrations due to water shortages and threatened agricultural production. Millions of people have been harmed by a lack of safe drinking water and severe heat strokes. Rising temperatures are anticipated to have an impact on the interior of the continent. Many plant species are expected to become extinct due to a lack of water supplies, increased glacier melting, altering weather patterns, and rising mercury levels (Sparrevik and Utstøl 2020). The coastal ecology is also endangered due to rising sea levels. Pakistan is among the most vulnerable countries due to a lack of strong infrastructure and appropriate adaptive capability. Aside from the concerns above, insufficiency of environmental knowledge and education, traditional consumer behavior, lack of incentives, need of legislation, and nonserious behavior of government increase the concerns of the general public towards climate change (Hussain et al. 2020). By 2050, considerable change in rainfall pattern and increase in mercury level around 2–3% can cause serious consequences. Environmental and natural disasters devastate Pakistan's economy, resulting in lower agricultural production, system rehabilitation, and infrastructure reconstruction. Furthermore, during the last 3–5 years, Punjab has faced many serious smog issues like illnesses related to the eye and skin and traffic accidents due to poor visibility (Hussain et al. 2020).

12 Impacts of Climate Change on Agriculture

Climate change affects agricultural output, altering crop productivity and yields in various ways that vary depending on the agricultural methods. Crop yields in tropical areas can be reduced because of climate change and rising temperatures; crops have already reached their heat and drought tolerance thresholds. Flooding, rising sea levels, and salinization of subsurface water are all expected to cause harm to the lowlands (Shaffril et al. 2020). Due to a lack of water for crops, decreased snowfall and rapid glacier melting can generate drought-like conditions. The climate is shaped by a warm and arid environment, which is a major source of droughts and floods; it significantly reduces agricultural production. The agricultural sector has the greatest vulnerability because of climate change impacts on it. In Indus Basin, rising mercury and changes in rainfall pattern are expected to reduce freshwater supplies, affecting Pakistan's agriculture industry and the overall economy. Furthermore, indigenous genetic crop types in the Indus Basin are on the edge of extinction. Water loss has also occurred due to the unavailability of sustainable practices for irrigation of agricultural areas.

13 Policy Measures for Adaptation

Vulnerability studies have a long history of identifying demographic groups more at risk to the negative effects of drought and natural disasters and negative consequences of political, social, and economic factors or conflicts (Anderson and Woodrow 1991). This study aims to target the best prevention strategies through early warning systems to avoid destruction (Lonergan et al. 1999). Furthermore, in recent years, required assessments of climate change vulnerability is increased nationally and globally (McCarthy et al. 2001). Indicators of vulnerability are required for the quantifiable measurements of vulnerability, and by using these techniques globally, we can prioritize the necessary measurements to overcome the negative consequences. To measure and assess the relative vulnerability of various regions, the community and policy-makers must adopt a set of standards (Cutter 2003). Policy-making is essential to increase resilience in response to vulnerability and facilitate adaptations (Eriksen and Kelly 2007). The major objective of this research is to outline important characteristics of change in climate that can indicate vulnerability and accomplish the policy assessment.

The standards have been explored to select the vulnerability indicators and to create the databases of vulnerability for the evaluation of the meta-methodological level (Eriksen and Kelly 2007). Recent studies of climate vulnerability incorporated that humans should focus on the regional and local scale, generally using a case study method (Jallow et al. 1996). The European Commission released its strategy to climate adaptation, which outlines a methods for raising European Union's readiness for present and future climate change impacts to a new level (Remling 2018). Despite examination and discussion of national and global adaptation strategies, a comprehensive analysis at the EU level is still lacking. It is important to consider that the EU sets the agenda for their 28 state member and serves as a key global hub for climate aid and development (Selin and VanDeveer 2015).

14 European Union's Adaptations

Adaptations are necessary for vulnerable developing countries, although they are relatively taboo in EU countries (Jordan et al. 2010). Accepting adaptation policies would stifle political resolve to reduce emission of GHGs and being "too soft" for mitigation strategies would reflect negatively on the EU. This mindset began to shift in the 2000s, after the third report of IPCC in 2001, which emphasized that adaptation is necessary for both industrialized and developing countries (Jordan et al. 2010). Since 2007, the commission has announced several nonlegislative adaption policies. In the mid-2000s, the first green paper was written that included information on some climate-sensitive sectors such as fisheries, biodiversity, water, and energy which already had EU-level policy instruments in place (Remling 2018). EU adaptation policy analysis consisted of the following:

- Social logics:
- Economic rationality is based on a social logic that may be expressed as structuring the European adaptation policy. It highlights the numerous coordination between adaptability and economic growth. Economic factors are the most compelling reasons the EU should take adaptive measures. There are two types: first, taking early actions can prevent economic harm and save money in the long term, making it a cost-effective option. Second, adaptation results in creation of new markets, which can boost "sustainable products and commerce services" (Remling 2018).
- Political logics:
- Adaptations are associated with current policy challenges, for example, energy security, disaster risk management, economy, and industries. Policies have a crucial role in the implementation of the new plan, as well as in legitimizing adaptation to audiences who may be doubtful of such emerging plan. Setting new challenges, such as adaptability, with well-established and widely accepted policy areas, is a common approach employed by powerful organizations to limit the development of alternative policy perspective (Glynos and Howarth 2007).
- Phantasmatic logics:
- The study of phantasmatic logic demonstrates how progressive and nonprogressive possibilities exist. For the EU, it contains four supporting storylines in all three publications linked to the social logic of economic rationalism: creating commercial benefits, cost savings, managerial supremacy, and worldwide leadership. Taxes provide security if the EU successfully executes adaptation (European Commission 2013). Third, the strategies recommend reclaiming control over threatened "EU territory" by identifying "knowledge gaps" that need to be addressed by depending on "solid scientific and economic analyses" (Glynos and Howarth 2007).

Climate change is a visible, quantifiable, predictable problem, and managing it through policies can successfully provide a sense of control (Rutland and Aylett 2008). Over the last few years, climate adaptations have gained significant attention. In that case, mitigation measures were aimed to decrease global warming by lowering greenhouse gas emissions. Furthermore, there has been an increase in the realization of climate change effects that can be devastating and cause societal disruption (Driessen and van Rijswick 2011). Climate change consists of a broad range of societal effects, as well as threats to water security, biodiversity loss, economic harm, and other effects on other social sectors, including human habitats (urban heat stress, urban flooding), agriculture (rural flooding, salinization and aridity), disruption of infrastructure, and food supply risk due to lower production of agricultural products. In recent years, public health issues have received increased attention (Costello et al. 2009).

On the other hand, climate change is not a concern; it may also present chances for new economic growth, such as in agriculture growing alternative crops. Adapting climate change is difficult for various reasons (Mees and Driessen 2011). As change in climate is a worldwide phenomenon, which needed international collaborative actions, and because the national, regional, and local consequences indicate the issues, they are either the outcome of applying adaptation measures or the effect of doing nothing to avoid consequences. People expected from government to protect them against floods, droughts, and the effects on health due to climate change.

Consequently, climate adaptation involves continual balance of short- and long-term actions and planning. Climate change adaptation is not just a technical issue but also a complicated societal transformation process that should be investigated (Termeer et al. 2011). The IPCC, which describes adaptation as "the adjustment of human or natural systems in response to existing or predicted climatic influences, which mitigates damage and useful for good opportunities," is one of the most commonly used definitions of adaptation to climate change (Change 2007). Adaptation methods are used for the prevention and mitigation of climate change effects on present and future generations. According to Adger and colleagues, the three foundations of adaptation are used to lower the system's sensitivity towards climate change; adjust the exposure of the system to climate change, and raise the resilience of the system to cope with changes (Adger et al. 2005). The terms "vulnerability" and "sensitivity" are frequently used interchangeably (Adger 2006). Resilience is a term that originated to address variations in balance to ecological systems (Folke 2006). Recent research has used partial equilibrium models and computable general equilibrium to evaluate the expected implications of climate policy interventions on agricultural productivity (Banse et al. 2008).

15 Conclusion

Although these and other model applications give helpful insights for global and regional policies and decision-making, more detailed data is necessary for significant focused policy actions. Assessing the impacts of climate change scenarios at more localized levels is an important research goal in this context. Calculating the carbon shadow price in agriculture and cost-benefit analysis of adaption programs is essential. These strategies are required for the development of effective policies which can increase agricultural resilience to climate change in different situations. In vulnerable populations, climate change adaptation and mitigation strategies are essential to protect the human society and their rights and promote justice in society.

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Sustainable Development Goals and Governments' Roles for Social Protection

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Abstract Both social protection (SP) and climate change (CC) adaptation seek to safeguard the most vulnerable persons as well as to promote resilience. The Sustainable Development Goals (SDGs) are combined to identify that action in an area affects outcomes in others and that development must balance economic, social and environmental sustainability. Developing countries are determined to prioritize progress for those who are furthermost behind. The SDGs are planned to finish the hunger, poverty and discrimination against girls and women. SP needs to pay extra attention to the long-term threats posed by CC. Similarly, social protection can pro-

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_12

vide such programmatic and policy options which have not been fully taken into consideration by adaptation. Adaptive SP includes a long-term perception that studies the varying nature of CC stresses and shocks. Other characteristics of adaptive SP include giving importance to protecting and transforming productive livelihoods, as well as adapting to CC situations instead of only reinforcing managing mechanisms. However, the adaptive SP structure analysis does allow the identification of various prospects for future work that relates these connected fields together. These include developing tools and resources, e.g., climate risk assessment for use with SP programmes, engagement in international and national conferences and events, funding of adaptive SP and integration of SP with adaptation funding and vice versa.

Keywords Social protection · Climate change · Sustainable Development Goals

1 Introduction

In September 2019, heads of state and government met up at the Sustainable Development Goals (SDGs) conference to reintroduce their assurance to implement the 2030 Agenda for SDGs. For this, they perceived that the initial 4 years of its execution had included significant progress; however, in general, the world was not in the right way to achieve its responsibilities to SDGs by 2030. The inventiveness, expertise, financial and technology resources from all of society are important to accomplish the SDGs in all situations. The importance of introducing climate change (CC) mitigation measures is being progressively understood and has become a policy significance worldwide (Akram et al. 2018; Majeed et al. 2021; Mubeen et al. 2021). Initiated by international agreements, countries from all over the globe and across all income groups have been committing to greener growth models and policies, aiming to reduce the global level of greenhouse gas emissions (Sabagh et al. 2020). Current new innovations, for example, 'SP through a livelihood lens', 'adaptive SP' (Parry et al. 2007), 'CC adaptation' (Davies et al. 2008a, b, 2009a, b; Ali et al. 2019a, b, 2021; Wang et al. 2019; Hashmi et al. 2020; Bukhari et al. 2021; Mehmood et al. 2021; Irfan et al. 2022) and 'climate resilience' and 'the social dimensions of CC' (Devereux 2006), have assisted in strengthening relations between SP and climate concerns (Hussain et al. 2020a, b). These have been coupled – in social protection – with programme and policy approaches privileging livelihood support to vulnerable households and/or focusing on social transfers, social safety nets and food security as part of overall poverty reduction strategies (Bonfiglioli and Watson 2011; Fahad et al. 2018, 2019; Daron et al. 2021; Ahmed et al. 2022).

Early exploration of the effect of CC on the poor helped pave the way to greater analytical integration between social protection and climate change, while a growing literature has helped to define common issues more clearly; strengthen awareness of interrelated risks, vulnerabilities and adaptive capacities; and identify priorities for research and action (Oswald 2009; Awais et al. 2018; Nasim et al. 2018a, b; Hussain et al. 2020c). Some literature has pointed to the importance of bringing in other distinct streams of thinking and action around, for example, smallholder well-being and agricultural development as well as disaster risk reduction (Jones et al. 2010; Hussain et al. 2021; Kirchmeier-Younget et al. 2019; Aleksandrova and Costella 2021).

However, most plans, policies and intercessions continue to be carried out and developed in distinct silos. National SP strategies, for instance, frequently neglect ecological problems, though emerging National Adaptation Programmes of Action (NAPAs) to CC scientifically neglect SP concerns (Vu et al. 2021). While part of the problem may stem from remaining conceptual weaknesses in sustaining a holistic view of risks, vulnerabilities and the integrated strategies required to address them, other challenges arise from the compartmentalized nature of development planning and implementation in a sectoral world (Nasim et al. 2012a, c; Sultana et al. 2013; Shakeel et al. 2014; Adnan et al. 2018; Hussain et al. 2021). This can have the effect of creating what can often seem to be impermeable boundaries between, for example, social, economic and environmental ministries and their international technical support agencies which must come together to address common issues linking SP and CC (Janzen et al. 2021; Malerba and Wiebe 2021; Akram et al. 2022).

2 The Sustainable Development Goals in Developing Countries

The SDGs, also known as the Worldwide Goals, were implemented in 2015 by the United Nations as a worldwide call to action to reduce poverty, secure the planet and ensure that all people enjoy prosperity and peace by 2030. The 17 SDGs are unified – they perceive that activity in one region will influence results in others and that improvement should adjust the economic, social and ecological maintainability (Table 1). Nations have resolved to focus on progress for those who are uttermost behind. The SDGs are planned to reduce poverty, AIDS, hunger and judgement against girls and women.

The technology, know-how, financial resources and creativity from all of society is essential to accomplish the SDGs in each specific situation. Home to 66% of the world's population and a portion of the world's biggest economies, the area kept up with economic growth rates of greater than 5% each year in last few years. This development helped lift billions of persons out of outrageous poverty, yet when the SDGs were taken on in 2015, 273 million individuals in the area were all the while living on under $1.90 every day and a further 1.1 billion were living extremely near the poverty line on under $3.20 each day, at high danger of being pushed back under it. As wealth has expanded, so have imbalances, and advancing more impartial development that at the same time progresses SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities) is fundamentally important assuming the area is to really

Table 1 The Sustainable Development Goals in developing countries

Goal 1: Eliminate Poverty
Goal 2: Zero Hunger
Goal 3: Establish Good Health
Goal 4: Ensure Quality of Education
Goal 5: Achieve Gender Equality
Goal 6: Management of Water and Sanitation
Goal 7: Adorable, Reliable, Modern and Sustainable Energy
Goal 8: Sustainable Economic Growth and Decent Work
Goal 9: Increase Innovation, Infrastructure and Industry,
Goal 10: Reduced Inequality
Goal 11: Sustainable Communities and Cities
Goal 12: Responsible Production and Consumption
Goal 13: Climate Action
Goal 14: Life Below Water
Goal 15: Life on Land
Goal 16: Peace, Justice and Strong Institutions
Goal 17: Partnerships for the Goals

Source: Asia-Pacific SDG Partnership. 2020

abandon nobody. Issues of ecological supportability, for example, water and air contamination, CC, imbalance and absence of resilience to normal risks, are tremendous difficulties across the regions. Investigation recommends that, by and large, countries in Asia and the Pacific have gained more headway on the SDGs starting around 2015 than other regions of the world.

3 Implementation of the Sustainable Development Goals

Countries in Asia and the Pacific are involved effectively in the intervention of the SDGs, and most have taken a range of measures to implement them. All around the world, progress is explored through the High-Level Political Forum (HLPF) on SDG, where countries are asked to show volunteer public surveys of their progress in applying the SDGs. Nations have focused on the SDGs in their outlining of difficulties of public development and commitment with advancement considerably varies. However, a range of measures have been sustained and taken to help national implementation of the SDGs. About 23 have recognized intragovernmental and multi-stakeholder mechanisms to help the plan, while others are utilizing existing mechanisms. Most countries have started to adjust and integrate their national strategies with the SDGs, and almost 30 have distinguished central issues of combination between their national improvement plans and SDG indicators and targets. Ten countries, which include the ADB Approach of Bangladesh to the SDG 7 and

Indonesia, have established primary road maps and plans for SDG execution, setting out national goals for the SDGs.

Countries can reflect and share on aggregate progress toward the SDGs as well as can contribute in coordination and collaboration opportunities. For instance, the Asia-Pacific Forum on SDG calls regional members once a year for this purpose, conversant by subregional discussions on certain themes. Such gatherings, for example, can play a significant part in renewing advancement toward the SDGs in the consequence of the COVID-19 emergency.

4 Social Protection Tools and Frameworks

- *Precautionary strategies* are community measures to decrease the likelihood of hazard. In the market, precautionary storage resource management (SRM) mediations are outfitted toward improving the abilities and the working of labour markets to decrease the danger of low as well as under- or unemployment.
- *Mitigation strategies* reduce the effects of possible danger. Typical moderation methodologies are protection of portfolio, variation and supporting. Correspondence arrangements of action in communities and families are instances of informal protection plans (Dutta and Fischer 2021).
- *Coping strategies* release the load of hazard whenever it has happened. The government plays a significant role in helping people in adapting, like when individual families have not saved to the point of dealing with catastrophic dangers and major illness.
- *Protective measures* give release from deficiency. Protective measures are barely designated security net measures in the traditional sense – their goal is to give help from deprivation and poverty where defensive measures have failed. Protective measures with social protection help the frequently poor, particularly the individuals who cannot work as well as earn an income. This compares most intimately with standard social well-being (Birchall and Bonnett 2021).
- *Preventive estimates* try to stop deprivation. Preventive estimates manage poverty mitigation. They incorporate social protection for vulnerable groups (with respect to economics), people who have been victimized or may fall into poverty; they may require backing to assist them with poverty shocks. SP programmes allude to formalized frameworks of annuities, medical coverage, maternity advantage and joblessness benefits, frequently with three tripartite financing by businesses, workers and the state (Nguyen 2021).
- *Promotive estimates'* objective is to upgrade real incomes as well as capacities of the poor people and weakest populaces while remaining stuck in SP targets. They are accomplished through a scope of livelihood-enhancing programmes focused on families and people, for example, microfinance and school feeding.
- *Transformative estimates* try to address susceptibilities emerging from social disparity and rejection of the poorest as well as most relegated groups.

Transformative ways to deal with SP are consequently comprehensive like rights-based approaches (Janzen et al. 2021).

The emphasis on development is significant as it shows the solid linkage among livelihoods and SP.

5 Social Protection Mechanisms for Climate Change and Adaptation

The SP mechanisms can be adjusted to react to explicit vulnerabilities emerging out of climate- and environment-related risk, through specific measures planned as follows:

Social transfers can be explicitly intended to bolster undermined livelihoods by giving no safety nets in times of natural crisis and food protection, yet offering families the potential for longer-term investment. Ordinary transfers over an adequately significant long period can permit weak families to both meet their urgent necessities and develop resources (Khaliq et al. 2012; Sajjad et al. 2012; Nasim et al. 2012a, b, c; Islam et al. 2021). They serve numerous elements of assurance, avoidance and advancement, especially when joined by different measures connected to rural development and specialized outreach support to advance development and financial stability for beneficiary families. Contingent upon natural and economic situations, transfers can appear as animals, agrarian instruments or money for long-term investment (Hammad et al. 2010a, b; Hanlon et al. 2010; Usman et al. 2010; Wajid et al. 2010; Nasim et al. 2011; Kulin and Johansson Sevä 2021; Hussain et al. 2022).

Subsidized sale of agro-pastoral inputs can be coordinated to farmers living in regions of important ecological danger but however who are able to rely upon their own useful resources. This takes into account security to avoid negative coping approaches like misery sale of land and animals and furthermore helps guard against over-double-dealing of and strain on regular assets, like forest products. However, a few ambiguities persevere in the focusing on and the administration of the programme, and discussion proceeds over the prudence of such large-scale public intervention in agricultural sectors and sponsorship programmes keep on being a choice considered by various governments (Nasim 2007, 2010; Ulrichs et al. 2019; Singleton et al. 2021).

Social protection components built upon seasonal dimensions of vulnerability and risk offer potential to facilitate smallholders. Pastoralists living in risk-hit regions against the most exceedingly awful shocks of production are failure connected to environment conditions. Weather-indexed crop insurance is one such measure (Ali et al. 2019a, b). Climate-indexed crop protection is one such measure. The protection ensures the loan permits low-income as well as high-risk-prone farmers to get credit for purchasing seeds and different agricultural inputs for higher-yielding crops. Since the poor are the most helpless against sudden environment-based production failures, such protection addresses a genuine type of 'protection against poverty' and becomes, in this manner, an instrument of social justice (Wajid et al. 2007; Ahmad et al. 2009; Usman et al. 2009; Costella et al. 2017; Abdoul-Azize and El Gamil 2021; Din et al. 2022).

Social protection for the nutrition and health impacts of seasonal CC and environmental change and degradation is often overlooked in both social protection policies and programmes and climate change strategies. Social insurance for the nutrition and health effects of seasonal CC and ecological change is frequently disregarded in both social insurance arrangements and programmes and environmental change-related techniques. However, the connections among environment and health are notable and are by most records intensifying. SP measures – uniting services of health, climate and social welfare – can incorporate strengthened vaccination campaigns in regions and among populations at most serious risk (Aleksandrova and Costella 2021) (Fig. 1).

Public works programmes can be specifically designed to include the organization of rewarded seasonal labour-exhaustive activities taking place during the 'peak' periods of the year, in order to avoid interference with local agricultural work. While providing beneficiaries with income to protect their livelihoods and productive assets, this activity will also address local environmental, economic and social priority needs. Such programmes include most of the sustainable land and water management activities as well as other complementary activities (such as those related to sanitation and hygiene of the habitat, wastewater drainage, management of domestic waste and preservation of collective economic and social facilities,

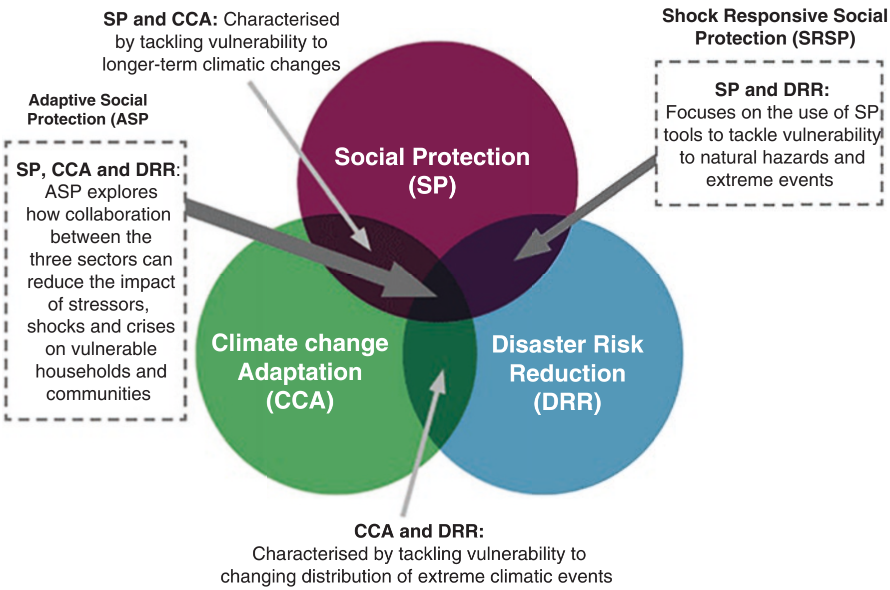

Fig. 1 Adaptation of climate change with relation to social protection

environmental services, protection of wildlife and protection of biodiversity; Aleksandrova 2020).

Strengthening essential socio-economic infrastructure Comprehensive social protection depends as much on the supply of essential social and economic services and infrastructure as on demand; while a number of the specific social protection measures outlined above aim to enhance demand by supporting the capacity of vulnerable groups to access services, complementary efforts must be made to ensure the provision of strong, functioning and quality services in the first place (Hussain and Karuppannan 2021). In geographic areas particularly prone to climate risks and hazards, however, additional efforts are needed to (i) enhance environmental infrastructure and natural capital and (ii) bolster social infrastructure against climate damage. Protection and rehabilitation of socio-economic collective facilities located in areas with high climate risks would include, for example, more weather-resistant health centres, nutrition centres for children, water supply systems and infrastructure, as well as food storage services (Gammage and Stevanovic 2019).

6 Responsibilities of Government for Social Protection

Given the great breadth of strategies which connect to SP, it is not especially expected that this institutional fragmentation should happen. In many countries, SP strategy, whether narrowly and broadly defined, includes a confusing range of governmental institutions and policy actors. This obviously makes a significant challenge for government structures as far as strategy improvement is concerned (Zahoor et al. 2019).

Without going into this issue in detail, the following points can be made:

- A powerful database is vital to consider public approach to draw in with the real factors of vulnerability and deprivation.
- In furthermost situations, it is necessary that departments of government other than specialist social welfare agencies (such as the ministry of finance, planning commission, cabinet office) become centrally involved in the development of public policy in developing countries.
- Social protection policy will be supportive in brokering the significant range of interests involved and coming to an appropriate view on the state's role, resources and priorities. This implies that governments need a central location to develop capacity in poverty analysis and monitoring, in general, and in the development of social policy more broadly (Ulrichs et al. 2019).
- Greater recognition is needed for the relative benefits of regional *governments and decentralized structures* in addressing both social protection and climate change, accompanied by measures to empower such structures in planning, implementation and monitoring of responses. The social protection effects of climate change and variability are often very highly localized (Masood et al. 2022).

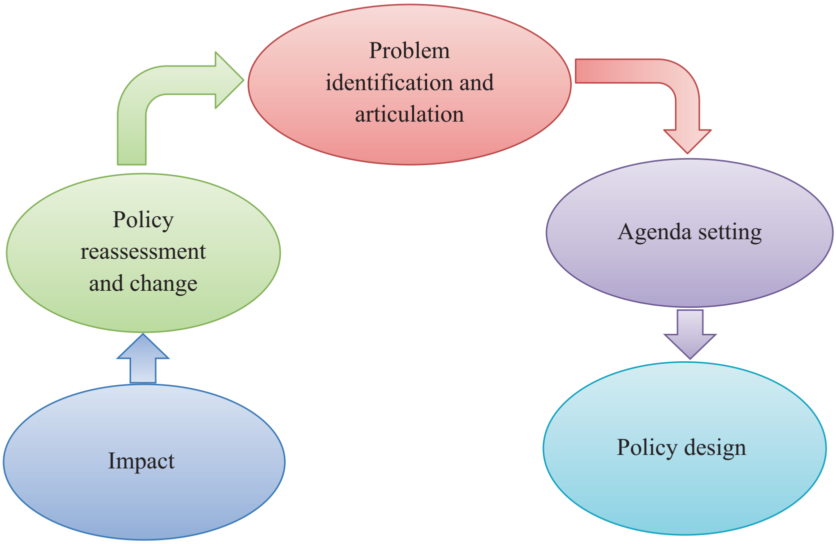

Fig. 2 Implementing social protection strategies

- *Strategic partnerships and effective coordination* are key to the success of efforts to integrate social protection and climate change policies and programmes within broader overall national poverty reduction and development strategies. This will require enhanced capacity and effective institutions at national and local levels (including grassroots institutions and local governments; Fuo 2019; Naz et al. 2022) (Fig. 2).

7 Conclusion and Future Recommendations

SP can be viewed as a part of variation involvements, as it copes with both vulnerability and response capacity, specifically the transformative, promotive and preventive, parts of SP. Like CC, SP purpose is to manage the risk and decrease vulnerability, and it does it mostly by building both financial and productive assets. Integrating CC into SP would mean comprehension in which ways SP involvements can possibly contribute to variation. This has been established as a different method, called 'adaptive SP'. SP might actually help with conveying transformation help to the poorest and the most powerless, though with CC there arises some risk; it will not come to the poorest. A subsequent thought is the impact that CC will have on existing SP frameworks in developing countries and what progressively erratic climate implies comparable to the requests put on SP frameworks and the sort of help they offer to vulnerable and poor people.

It is necessary that recent achievements be safeguarded to the maximum possible extent and a true transformative recovery after COVID-19 be followed, and such recovery should reduce the menace of future disasters and bring much closer the inclusive and sustainable development needed to achieve the goals set by the 2030 Agenda as well as the Paris Agreement.

Strategies that recognize and enhance these synergies at the outset, from initial analysis and policy development through programme planning and implementation and evaluation, would seem to offer the greatest potential for positive impact on vulnerable populations facing a multitude of risks.

That said, instead of awaiting perfect policy integration (which often seems chimerical in the fact of the plethora of competing frameworks, scientific disciplines, institutional interest groups and bureaucratic structures with often contradictory agendas and priorities vying for prominence), approaches that are incremental and, themselves, 'adaptive' to the particular national policy environment may be the most pragmatic way forward. Such approaches would seek to build on, rather than replace, those elements of existing policies, programmes and structures whose mechanisms can be fine-tuned to respond to the newly identified priorities. In this way, perhaps, climate resilience measures can become increasingly open to social protection responses, and social protection itself can be brought ever more firmly down to earth.

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Integrated Farming Approach

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Abstract Integrated farming system is a system where a variety of crops and animals are kept together in order to minimize the investment and efforts. At the same time, both resources (water and land) are utilized for maximum output production. There are various types of integrated farming systems, where the livestock, fishes, and crops are collectively grown to utilize the solo water sources. If fishes are stocked with the plants only, then that system is termed as "aquaponic system." However, the rich water nutrients, as a result of fish waste, are used as fertilizer for the plants. Hence, such system balances the ecosystem and is considered an environment-friendly system. Such system not only improves the socioeconomic condition of farmers but simultaneously assists to better address sustainability concerns. Along with food challenges, the world is also facing land shortage and water crises. There is also low supply and high demand of aquatic protein in the market. However, water is a major source of aquatic protein that covers about 75% of the earth. Unfortunately, these resources, in maximum cases, are ignored in terms of production. The integrated fish farming systems (IFFSs) are self-sufficient and less effort systems where the cycling of waste from one farming system to anther farming system is used as an input. IFFS is one of the aqua- and agriculture systems that provides a continuous source of income from the different components, resulting from efficient water and land usage. IFS is progressively strong to weather fancies and moderate climate change.

Keywords Integrated fish farming (IFF) · Food security · Biodiversity · Self-sufficient farming · Ecological sustainability

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_13

1 Introduction

Integrated agriculture and aquaculture or agro-pisciculture is also termed as "integrated fish farming" (IFF). IFF was initiated about 2400 years ago in China and 1500 years ago in India (Othman 2006). Through the integration system, local economy may also be improved and healthy diet might be available by producing a variety of food. It also increases the outcome and produces many other by-products. Hence, such type of system has various other advantages including water and land space utilization. Water saving is a major advantage of the system that depends on the installed system as recirculation with the biological purification system in fish farming. Aquaculture is a rapidly growing sector of food production around the world by regularly sharing human food, protein requirement, improvement, and rural development, exponentially demanding more and needing extra resources such as energy, water, health facilities, food, and many others due to the increasing human population worldwide. The integrated fish farming is a valuable method model of how vegetables grow, where there is a decrease in the cost and increase in the profit. Such diversity imparts stability in production, efficiency in resource use, and conservation of the environment. Hence, modern techniques have high external input having a high capacity for maximum use of resources and decrease pollution. Waste recycling and best water management are the major advantages of the system. Hence, IFF ensures both the economy and food. Somehow, small-scale IFF systems might provide a reasonable rural livelihood, a clean conserved environment, and adequate food, fuel, and fiber products. It is essential to focus on increase production and profit, per unit area, by utilizing common resources as well as conserving natural resources for the rapid growth of rural areas around. At the same time, the quality and competitiveness also must not be ignored to achieve the target.

2 Aquaculture and Food Security

There is a food security challenge all around the world, especially in developing countries, due to the rapidly increasing human population. The natural resources are decreasing significantly due to overexploitation and the market demand is increasing, on the other hand. It was predicted by the World Food Summit (1996) that the number of undernourished might be increased up to 410 million by the year 2015. The UN Millennium Development Goals (September 2000) reported 1134 million people subsisting on an income greater than US$1 a day; that number represents 25% of the world.

The aquatic food supply is slower in the market, because the natural resources are overexploited and the human population is growing faster than the market supply, except China, while per capita consumption is also decreased, due to many reasons, from 14.6 kg (1987) to 13.1 kg (2020). The aquatic food contributes more than 15% in global food security as compared to the animal supply. However, modern technique adaptation increased from 31 to 41 million tons and 88–96 million tons per year and fluctuation has been recorded from natural capture all around the world (FAO 2002). Hence, diversified and intensified aquaculture production has expanded for the last three decades. Therefore, for the economic growth, improved living standards, and trade, there is an utmost need of aquaculture development, especially IFF, for domestic food security that will contribute towards global safety (FAO 2000).

3 Integrated Fish Farming and Economy

Integrated fish farming (IFF) is one of the integrations systems that is varied and diversified in nature. Therefore, it cannot be overemphasized. However, in the farming enterprises it is one of the profitable, most reliable, and viable. In many of the communities, especially rural areas, IFF plays an important role on economic empowerment, because of the routine production system around the year with optimum production. Hence, the following are the contributions of IFF to food security and self-sufficiency:

3.1 Food Security

In spite of enormous natural as well as human resources, many developing countries (Nigeria, India, Philippines, and China) are affected by poverty, hunger, and deprivation (Alamu et al. 2004). Therefore, sustainable and adequate food security will be guaranteed through the development of an oriented farming system to overwhelm the economic crisis situation around the world. The proteinous food supply, considering the limited available resources, needs to be tackled seriously. Hence, considering the scope of IFF, serving as a combined cultivation of crops with rearing of livestock and farming of fishes, offers hope widely for increase in food production. However, the IFF system not only is an enough source for producing higher production but also produces vegetable, meat, eggs, and milk for human consumption.

3.2 Superior Income Sources

There is a significant source of regular income through the IFF system. The poultry-cum-fish farming is the best fit example of a regular generating income and it is a daily basis from various farm products, as before the harvesting of the fish production, the farmers collect and sell the eggs to the market to earn money. On the other hand, another best example of generating income on a daily basis is the selling of vegetables, produced from the IFF system. Hence, a farmer can earn money and harvest the crop on a daily basis instead of waiting for months to harvest the fishes to market. However, such practices of the IFF system provide a steady source of income throughout the year. Therefore, integrated fish farming is more profitable than the unitary system of farming (Nnaji et al. 2003).

3.3 Self-Sufficient Farming

Creating job and business opportunities is the best property of IFF that are more attractive and advantageous than the unitary system of fish farming (Davies et al. 2008). This exercise is very suitable to poor farmers because this system has low spending and more output of dietary or food items (Ayinla 2003). Even in the dry season, crops as vegetable, in the IFF system, water from the pond is used to water the vegetable crop adequately. Hence, harvesting also does not stop at any season. Likewise, the time is utilized in various activities during the IFF system to make the community engaged in earning money, hence making the community self-reliant and productive all year round.

3.4 Employment and Job Opportunities

Crop and fish farming together create a lot of employment opportunities to farmers and rural youth. The development of employment possible under the IFFS is diverse from 30% to 48% (Shankar et al. 2018; Ajana 2003). Creating different jobs are dependent on the grouping of the enterprises selected (Table 1). The nonstop worker requirement for several integrated culture systems creates jobs and higher employment to public. During the pandemic (COVID-19), reverse migration (urban to rural) was observed, which increased the need of employment in rural areas. However, integrated farming was one of the activities that continued throughout the year. Likewise, IFFS not only provided job opportunities for migrants but farmer

Table 1 Employment chances provided by the integrated fish farming system

Possible areas	Job opportunities
Livestock and food component	Maintaining plants and fish Keeping food storages, beans, and supplier
Organic waste supplier	Manufacturing organic supply Making sure markets supply chains Worth adding to organic produce to grow the revenue
Agro-ecotourism	Connecting traveler to agricultural lands, growing gardens, park, fish farm house, fishing hunting, fish spawning
Staff management	Growing and stocking juvenile fish and plant caring Involving production of seed to make good bazaar rate Identifying and maintaining various important plants and fish species

families were successfully busy in farming throughout the year to earn. If we look into other industries, businesses almost remained suspended during the COVID-19 period, but only the farming system developed and progressed.

4 IFF and Ecology

In general, integrated farming is practiced on some described principles consisting of the various ecosystems (Othman 2006). Even the sustainability of agriculture is based on an eco-friendly production system (Dhawen and Kaur 2002). The nutritional cycle, which is consumed or utilized by one individual to other, is the best worth of the IFF system. For example, fish and animal waste is utilized as fertilizer by the plant crop and in return the by-product of plants is utilized by the both animal and fish in the integrated system. Hence, the plants produce feed for fishes in the pond again and fish waste increases its fertility and makes nutrients available for the crop (Prein 2002). Subsequently, the ecosystem becomes ideal and sustainable as well as environment-friendly and some ecological efficiency of an IFF is discussed below:

4.1 Fertilizer

In integrated fish farming, basically fertilizers are produced by animals or poultry in the fish ponds which increase the fertility of water. In result the production of fish increases significantly. Correspondingly, when poultry waste is utilized in the IFF system, then wasted food of the shed that contains 10–30% protein (energy between 110 and 1400 kcal per kg) is utilized too (AIFP 2005). This contains undigested feed and microbial synthesis, resulting in residues and metabolic excretory products, which could be utilized by replacing reasonable parts of raw feed in fish farming (Fashakin et al. 2002). Hence, this functions as manure and will result better than chemical fertilizers in the fish (Ansa and Jiya 2002). Hence, management needs a plan to stock the number of animals depending on the feed and fertilizer supply in the system. Further, the growth/production also depends on the age and weight of stocking animals along with the quantity/quality of feed/fertilizer supply. While a few fish such as tilapia hybrid ingests manure directly (Belay et al. 2016), along with this nutritional supply, it is essential to pay attention on the hydrophysicochemical parameters, because the growth and survival of fishes depend on the water parameters such as oxygen, pH, nitrites, and salinity.

4.2 Nutritional Cycle

In order to achieve the economic benefits and ideal environment in the fish culture system, recycling of organic waste plays the most important role. Hence, the recycling system not only reduces the expenses of feed and fertilizer but also has an important role in the sustainability of aquaculture. Likewise, the farmers reuse the bioresource flow in such culture system. However, in the first step it is essential to estimate the bioresource flows by determining the expected utilization of cycling biomaterials in the integrated system (Boland et al. 2013). However, to some extent, the resources that are efficiently recycled cannot be adequately expressed (Esayas et al. 2020). Therefore, in the IFF the farm must be well managed for effective cycling of nutrients. The nutritional cycle is also dependent on the type of farming and level of integration. The major objective of recycling is to utilize the cultural animal waste into a fertilizer to enhance the productivity of plankton (Dinku et al. 2017). In targeted poultry-cum-fish farming, the protein-rich chicken dropping is made available to the fish either directly or indirectly via the primary producers in the aquatic food web (Hiwot et al. 2016), which in most cases reflects the productive capacity of the ponds.

4.3 IFFS and Soil Health

Crop and animal systems in Asian countries' agriculture show a huge diversity in harvesting patterns, livestock species, and use of the source base. There is an indication of positive and economic profits from crop and animal integrating that indorse supportable agriculture and environmental safety (Herridge et al. 2019). In many economically developed countries, a high energy input in the form of excessive fertilizers and pesticides has resulted as pressure on intensive agriculture and environmental degradation. Sustainability of the farming process and the uses and reutilization of ideas present and that take part in the lowest wanted amounts of external inputs would be improving. IFFS stands the greatest supply organization plan to decrease dependence on the market for involvements, to progress the benefit of the soil (Hu et al. 2016; Paramesh et al. 2019). The livestock and fisheries play an important role in the recycling of nutrients and developing microbial movement during integration. Research shows the benefit of crop and animal integration in limiting plantation, managing nutrient, attractive organic practices, and waste material management.

4.4 Production Capacity

Planktons, either zoo or phyto, form the natural food in the pond for fishes, and the productivity is measured through qualitative or quantitative analysis (Lemma 2021). Hence, such productivity is termed as "biomass." Biomass is measured as the net community production/kg^{ha} (Mekonen et al. 2021). In the IFF, the animal waste, which acts as fertilizer in the pond, increases the productivity of such producers in the pond and in result increases the fish production per unit area (Oribhabor and Ansa 2006). In general, plankton production depends on the nature of manure and biomass production relies on input in the ecosystem (Mulokozi 2021). The soil quality along with hydrological parameters also has an impact on the biomass production and fertility conversion of food in the pond.

5 Ecological Sustainability of IFF

A sustainable ecosystem is most important for successful farming. Sustainability is an ability that never compromises the future generation on any aspect of need/welfare/development. However, some of the farming systems have been reported to cause severe social and environmental impacts (Olabode et al. 2021). Hence, considering the concern of overburdened ecosystems, a new approach of environment-friendly and sustainable aquaculture system must be practiced (Omogho and Eweto 2020). In poor management there is high organic load that leads to deleterious effect of cyanobacterial bloom. However, these blooms are undesirable and some species produce odorous metabolites. In result it affects the taste of cultured fish and causes toxicity in aquatic environment. Moreover, these and some other reasons call for serious attention to maintain the ecological sustainability of IFF.

6 Integrated Fish Farming and Biodiversity

Single farming practices seem to have multiple enterprise schemes, likely to improve conservation function, complete biodiversity restoration or rehabilitation, and extend the entire structure of agricultural production and economics (Fig. 1). Plant diversities and animal varieties in agricultural variation happen when a farmer expands more plants. The IFFS helps increase numerous harvests together as mixed crops, sequential crops, or intercrops. It might take in yearly, perennial crops or tree crops that deliver ecosystem services such as nutrient recycling, better soil quality, economic decline, water saturation, pollination, and nitrogen fixation from agriculture. IFFS also helps to increase microbial biodiversity in soil causing the accumulation of duck dropping manure in rice and fish culture. Hence, ultimately, there is

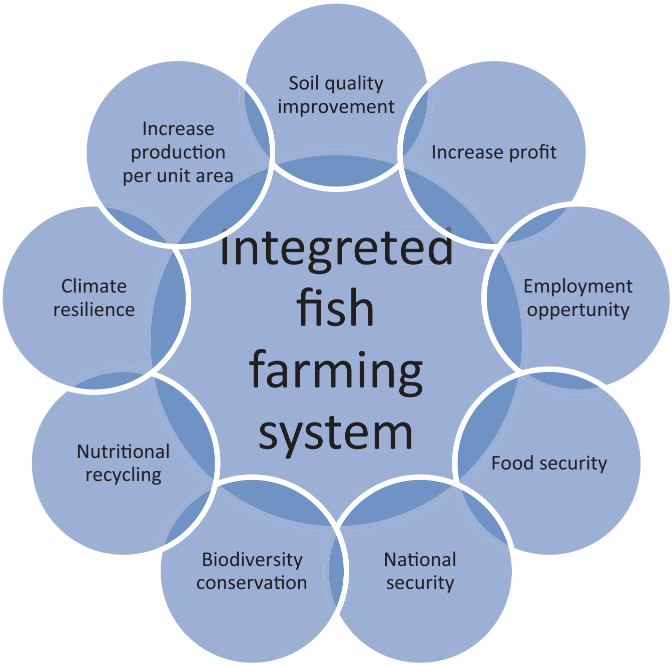

Fig. 1 Integrated fish farming system to provide ecosystem services

increase soil fertility (in terms of microbes) as well as water fertility (in terms of phytoplankton and zooplankton) that results in production increase (Nayak et al. 2018). IFFS also encourages polycultures such as annual continuity of flower crops, vegetable farming, and spice farming.

7 Income, Food Diversity, and IFF

There are multiple sources of income value in the integrated farming approach such as values from rice cultivation, animal husbandry, aquaculture, vegetables, orchard garden, and fish. It is estimated that the income generated through this system is about 53% of fish, 34% of livestock husbandry, and 13% of cultivation (Acosta-Nassar et al. 1994). However, fish production contributes a major income to households in the systems.

8 IFF and Modern Techniques

Considering all consequences and challenges in aquaculture, scientists and researchers are always ahead all around the world. All over the struggle is taken to reduce the operating and feed cost along with a sustainable system in order to increase the per unit area production. In the modern era where there is huge use of modern technologies that make peoples' lives easier and comfortable, together the modern approaches are also applied in the aquaculture sector. Nowadays, two major approaches are exercised in this sector. In one approach, pond enterprise is added to a farm system, where the system receives nutrients from other resources. Hence, such culture system is rich in linkage and resources, while in the other approach there is physical integration through design modification as well as operation. The best example of such practice is rice-cum-fish culture. Such market-oriented small- to large-scale integrated system is entirely exploited. In the IFF the plant waste or manure is utilized, smallholder or larger farmers, to increase the water fertility that boosts up the primary producers in the pond. In result, such waste produces microorganisms and develops the natural food for fishes, such as plankton, benthic organisms, and detritus.

9 Advantages of IFF

In general, the significance of the IFF is already mentioned above in detail in all aspects. However, some point-to-point importance is described below:

(i) Best recycling material utilization efficiency through various approaches
(ii) Reduces the operating cost as well as feed and fertilizer
(iii) Easy to control and operate
(iv) Increase per unit area production with sustainability
(v) Environment-friendly and balances the pond ecosystem
(vi) Provides employment opportunities and livelihood to smallholder farmers
(vii) Economically viable because of lowest input and higher output
(viii) Provides various sources of protein and vitamin simultaneously, along with the production of fish culture, vegetables, mushroom, fruits, grains, eggs, meat, milk, fodder, etc.
(ix) Poverty reduction capability
(x) Potential of socioeconomic uplift of public and country

10 Types of IFF

In general, the IFF is classified into the following two major farming types:

(a) Agri-based fish farming
(b) Livestock fish farming

10.1 Agri-Based Fish Farming

(i). *Paddy-Cum-Fish Culture*: About 3–8 months, the paddy field retains water and is considered suitable for fish stock. However, in IFF there is a need to pay attention and control the pesticides, which is used for protection of the paddy crop, in order to avoid any mortality in the fishes. However, there are various approaches in paddy-cum-fish culture which are discussed as follows:

(ii). *Perimeter Type*: Paddy grows in the middle.

(iii). *Central Pond Type*: Paddy growing area is on the perimeter.

(iv). *Lateral Trench System*: Trenches are provided on either one or both sides of the moderately sloping field.

The variety of rice used in this culture is *Panidhan*, *Jalmagna*, *CR26077*, *Tulsi*, etc., while the fish spp. are Indian major carps, *Channa* spp., *Oreochromis mossambicus, Clariasbatrachus, Anabas testudineus, Hypophthalmichthys molitrix*, *Ctenopharyngodon idella*, and *Cyprinus carpio*.

(v). *Rice Fish Production Practices*: Rice fish production practices (RFPPs) are those where the farming of rice takes place while allowing the synchronized or revolving presence of naturally present fishes and other aquatic organisms that are harvested through fisheries or introduced fish populations that are cultured. All over Asia, RFPPs have been established, continued, and been transformed under a range of environmental, social, and agricultural policy contexts and include diverse fish species and rice variations. RFPPs can make resourceful use of unusual water and soil resources, maintain biodiversity, control water flows and water quality, and reduce the requirement for agro-chemicals for rice production (Freed et al. 2020).

(vi). *Horticulture-Cum-Fish Farming*.

Whereas there is a culture of vegetables, fruits, and flowers together, fish farming is said as horticulture-cum-fish farming. Along with the fresh aquatic protein, other nutritive elements are also obtained through vegetables and fruits. These crops, selected based on season and soil quality, are grown on the dikes of the pond. Almost all plants are selected based on their qualities such a less shady, dwarf, and evergreen. The suitable fruit plants include papaya, mango, coconut, and banana. Meanwhile in the vegetables, turnip, peas, tomato, chili, and cauliflower are considered ideal. Flower crops such as *Chrysanthemum*, rose, marigold, jasmine, and *Gladiolus* are also useful to earn money from the market. Such type of integration provides more than 25% earning return than only the fish farming system.

(vii). *Aquaponics*

Currently, the resources required by the society for the food production systems are better quality or modified in order to provide. That is, lack of soil for agriculture is another developing issue to optimize the production of food. This is particularly attractive in waterless zones where water and soil decline. In this situation, aquaponics is being considered to take benefit of resources such as water, nutrients, and space shortages (Forchino et al. 2017; Wongkiew et al. 2017). Aquaponics can be defined as the integrated process in one recirculating environment of two methods: aquaculture and hydroponics. Aquaculture involves the raising of aquatic fauna, such as fish, crabs, and shrimp. Hence, about 560 species are being grown by this way. On the other hand, hydroponics is a crop culture technique that practices a water medium as a replacement for the soil to grow out vegetation.

The following gives a brief overview of IFF options according to input sources.

Plant-Based Sources of Pond Inputs

Plant inputs into fishponds are also termed green manures, which are usually aquatic or terrestrial macrophytes (Edwards 1988). Nutrient content and availability vary between different farm crops and those planted specifically for use as direct fish feed or as pond fertilizers. Those with high nitrogen contents are usually used as pond inputs. Legumes have high nitrogen content and farmers have to decide if they are to be used as pond fertilizer or directly as fish feed.

Various grasses are sources of feed for many herbivore fish species in the pond. Hence, such species as *Ctenopharyngodon idella* play an important role in the pond as “grass bio-processor.”

In return, poorly digested excreta of fishes work as fertilizer that enhance the fertility of the pond and increase biomass production of plankton and other microorganisms in the pond. Hence, such grasses save the greatest proportion of farming expenditure (Solomon and Natarajan 2019). At the same time, such farming system leads to significant increases in fish production.

10.2 Livestock Fish Farming

10.2.1 Poultry-Cum-Fish Farming

In the poultry-cum-fish farming, not only the production of meat or eggs is achieved but simultaneously the poultry waste and droppings function as fertilizer in the fish farming system. In this type of culture system, Rhode Island or Leghorn variety birds are considered as suitable in the farming.

10.2.2 Duck-Cum-Fish Culture

Ducks are considered as biological aerator due to their feeding habits in the waste and control of aquatic weeds. Ducks are stoked on the dike of fish pond with low-cost shelter construction. These ducks also feed on aquatic insects, mollusks, tadpoles, etc. and make a balanced ecosystem in the pond. Generally, these birds require a space of about 0.5 square meters.

10.2.3 Cattle-Cum-Fish Culture

In cattle farming, cows are considered as ideal animal for farming with the fish culture. However, its BOD is lower than other livestock manure and may excrete over 4000–5000 kg dung and 3500–4000 liter urine annually. For the one-hectare pond, about six cows for 300-fish stocking capacity. Hence, the annual output production is expected with 9000-liter milk and 3000 fishes annually.

10.2.4 Goat-Cum Fish Integration

The goats are preferred to rear with fish farming because the goat's excreta are considered as the best organic fertilizer. Goats are sensitive to heat; therefore, they need more attention than cattle. They also require a dry, safe, comfortable house. Their excreta contain organic carbon (60%), N (2.7%), P (1.78%), and K (2.88%), while their urine is rich in both N and P. Achieving about 3500 kg/ha fish production annually needs rearing of about 50 goats.

10.2.5 Rabbit-Fish Integration

Rabbit meat is popular due to its property of low fat content as compared to other animals. The animals are reared in cages or flow system in the fish farming system. Chinchilla, Grey Giant, and White Giant are the common breeds practiced with integrated farming system. Rabbit excreta contain organic carbon (50%), N (2%), P (1.33%), and K (1.2%), while its excreta contain high nitrogen. Therefore, its waste develops sustained plankton in the pond. To fertilize a one-hectare pond, approximately 300 rabbits are enough.

Non-Livestock Sources

The mulberry trees growing adjacent to fish farms are widely practiced in a few countries such as China. Whereas the silkworm droppings and waste pupae are utilized in the pond as fish feed, human night soil (e.g., from overhanging latrines above fish ponds and cartage), sewage, and septage have a long history of use in Asia.

11 Future Action and Conclusion

IFS is progressively strong to weather fancies and moderate climate change. Prevalently, the IFS is one of the best practices to cope with food security and unemployment issues. However, still there is a need to develop the small-scale integrated fish farming system model. Recirculatory aquaculture system (RAS), in-pond raceway system (IPRS), double recirculatory integrated aquaculture system (DRIAS), and Biofloc system might be introduced and facilitate the farmers to adopt such technology. Hence, all these systems have a best advantage that consists of the nutrient cycle. Further, government and nongovernment organizations must play their role and approach common people in order to support/facilitate the promotion of IFFS. Hence, such approaches not only will develop the economy at a local base but also will increase international trade.

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An Overview of Precision Agricultural Technologies for Crop Yield Enhancement and Environmental Sustainability

Hafiz Umar Farid, Behzad Mustafa, Zahid Mahmood Khan, Muhamad Naveed Anjum, Ijaz Ahmad, Muhammad Mubeen, and Huzaifa Shahzad

Abstract The socio-economic condition of farmers in developing countries demands to optimize the knowledge of precision agriculture (PA) technologies to maximize crop yields with minimum application of crop inputs. The amount of fertilizer applied and the method of its application are key factors to maximize the crop yield. However, conventional farming practices are unable to provide reasonable outcomes of the crop because of the unvarying fertilizer application over the crop. Several techniques and methods have been established all over the world to identify the spatial and temporal variabilities of physiochemical properties of soil during crop growth stages. The PA technologies consist of the global positioning system (GPS), geographic information systems (GIS), remote sensing (RS), variable rate application, guidance system, delineating site-specific management zones and active canopy crop sensors that assist farmers while taking effective crop management and input application decisions. However, one of the most efficient and effective ways for the site-specific N management is the application of active canopy sensor-based N optimization algorithms. These algorithm-based strategies not only tell instantaneous N requirement, but also forecast the in-season yields. The more efficient inputs applied efficiently the more will be the profit per unit area with less application of inputs through these sensors. These crop sensors, providing

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_14

instantaneous fertilizer rates at field scale considering soil nitrogen availability and crop growing patterns, are one of the best examples to utilize the time-saving approach. Therefore, the use of these sensors at the agricultural land should be promoted and subsidized in developing countries for the betterment of the agricultural system.

Keywords Precision agriculture · Development · Adoption · Technology improvement · Crop yield escalation

1 Introduction

The agricultural sector plays a vital role in the growth of economic progress of a country and affords the elementary necessities of food to manhood. The demand for food in developed and underdeveloped countries tends to increase with the increasing population rate and devastating climatic hazards. The growth rate of the country's economy gets affected if its agricultural system fails to meet the increasing demands of food supply to people. The need for a wide range of raw materials for industries is being met by agriculture and, most importantly, supports a country by providing food and other agricultural products, to fight against the numerous nutritional strains. In developing countries like Pakistan, major crops like wheat, rice, maize, sugarcane and cotton encountered 24% of value addition in the agricultural sector of the country. Respectively, 25,195 thousand tonnes, 7202 thousand tonnes, 6309 thousand tonnes, 67,174 thousand tonnes and 9861 thousand bale production of wheat, rice, maize, sugarcane and cotton were recorded in the year 2018–2019 as shown in Fig. 1.

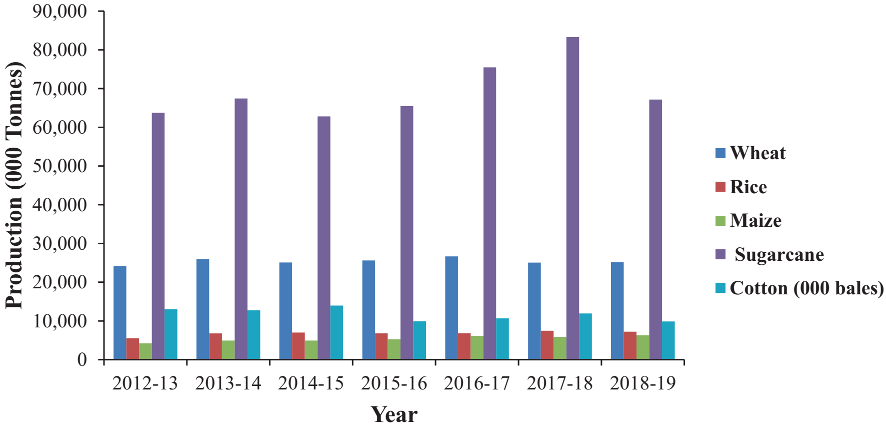

Fig. 1 Major amount of crop production in the last few years

Wheat is a chief cereal grain produced in the world, followed closely by maize and rice. Wheat is a significant crop in temperate zones and increasing demand in countries undertaking urbanization and industrial development. As a primary calorie source, wheat provides essential minerals, vitamins, amino acids and fibrous components to the human diet (Shewry and Hey 2015). The wheat production in 2018 and 2019 contributed 8.9% value addition in the agriculture sector of Pakistan. Wheat crop showed a marginal increase of 0.7% to 25.195 million tonnes over last year's production of 24.875 million tonnes. The area under cultivation declined by 0.6% (to 8740 over last year's 8797 thousand hectares). The annual wheat production declined by 4.1% when compared to the production for the previous 2 years. At the end of any specific year, less agriculture production was observed in the form of livestock, fruits and crops because of these traditional farming practices (Chandio et al. 2018). The wheat production according to PBS-2019 in the previous years is illustrated in Fig. 2. When compared to the previous year's crop production where the demand for food and fibre increased to meet the increasing requirements of the growing population, crop production in the last 7 years representing a yield of major crops is stagnant and decreased which may be ascribed to climate change (among other factors). It is a need of the hour to lessen the cost of production and boost crop production per unit of land. Therefore, based on the new technologies to minimize crop inputs, reduction in the environmental losses and increasing crop yield, precision agriculture appears to be the only fine-tune solution in the agriculture production system.

1.1 Precision Agriculture (PA)

The concept of precision agriculture is "Information-technology based approaches to collect or gather field crop data from multiple sources to make decisions associated with crop production". Estimating the decisions depending upon the

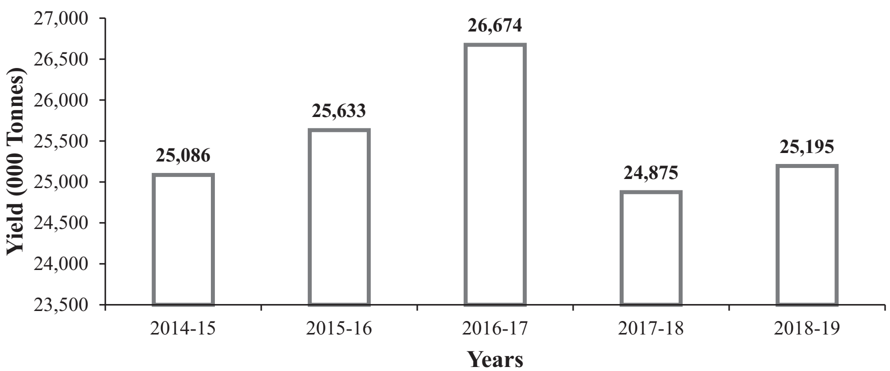

Fig. 2 Wheat production in the last 5 years

management of variability, sensing variability and managing variability are the elementary stages in precision agriculture. With all aspects of agricultural production within fields for near-optimal profitability, refining crop performances, shielding land resources, sustainability and conservation of the environment, precision agriculture objectives the application of technologies and principles to categorize, analyse and manage spatial and temporal variability (Zhang et al. 2002). Precision agriculture comprises various information tools like soil sampling processes, variable rate technology (VRT), geographic information system (GIS), remote sensing (RS) and yield monitoring (YM) tools (Ahmad 2013; Mahmood et al. 2013). The site-specific management zones are developed all around fields by utilizing field and crop-based information.

1.2 Relationship of Precision Agriculture (PA) with Digital Agriculture

The concept of digital agriculture is "Devices or tools which digitally gather, accumulate, examine, and provides electrical information and statistics to all value chains of agriculture". The use of various intellective digital innovations in the current agriculture system is becoming a growing global trend (Klerkx et al. 2019). Digital agriculture consists of several fundamental phenomena and the types of machinery comprise of immense facts and figures, robotics, integrated system advanced technologies, Internet of Things, artificial intelligence, 3D printers and digital twins (Smith 2019). This digitization has brought up a remarkable revolution and transformation in the agricultural sector through its production processes and techniques (Poppe et al. 2013). In most countries of the world, various shapes of ideas and philosophies emerged through digitalization in the form of smart agriculture (Poppe et al. 2013), decision agriculture (Nolet 2018), precision agriculture (Eastwood et al. 2017), digital agriculture (Shepherd et al. 2018) and numerical agriculture (Bellon Maural and Huyghe 2016). The major components in digitization or digital agriculture are described in Fig. 3.

However, in developing countries, the conventional farming practices depending upon general assumptions tend to increase the capital cost at the farm because of improper and inefficient use of chemical or fertilizers, raising serious environmental concerns (Prabakaran et al. 2018). The sole reason behind this unfortunate condition arising at the farm level is because of not implementing the abilities and the prospects of digital agriculture. The implementation of vast precision agriculture technology in various parts of the world like Europe, Australia, Canada and America has brought a serious revolution in their agricultural sector. In developing nations, the process of mechanization is currently very slow in the agricultural sector. However, the revolution that the world has brought with the implementation of new technologies and techniques is bringing a serious challenge for our agriculture to survive in these circumstances. Hence, the adoption of digital agriculture and precision agriculture techniques has now become the need of the hour for these countries.

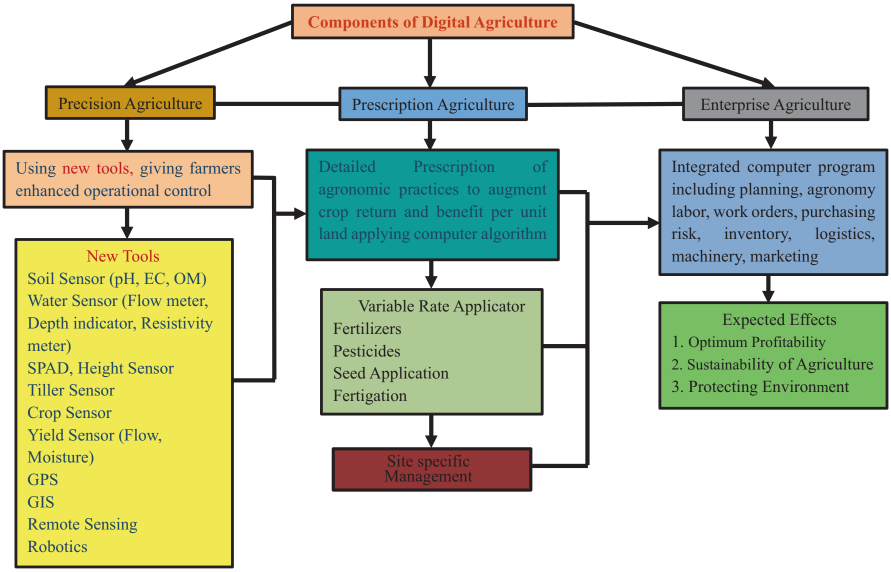

Fig. 3 Components of digital agriculture system

Farmers apply their crop inputs depending upon management zones using VRT with various varying inputs like seeding rate, fertilizer and pesticides (Ahmad 2013). Depending upon the goal of the end user in precision agriculture, varying input rates have two possibilities that either may increase or decrease the crop yield (Zhang et al. 2002). Labour cost at the farm level is lessened in precision agriculture by mounting auto-guidance systems like crop sensors on-field and tillage equipment (Adrian et al. 2005).

To meet the food demands of individuals, in agriculture, the increasing world population is becoming an alarming situation to reduce the enormous load on natural resources. To boost farm efficiency and crop production on the crop growth stage, the only productive solution is the implementation of precision agriculture technology while diminishing impacts generated on the environment (Awan 2016; Koutsos and Menexes 2019). The application of precision agriculture technology is still lacking in the problematic areas, where the occurrence of variability in soil nutrients exists spatially and temporally, crop retaliation to changing environment and crop yield environments (Andrade et al. 2010). At the farm level for the implementation of precision agriculture technology, comprehensive knowledge of yield-limiting factors is required, i.e. available soil water, sources of irrigation water, management of macro and micronutrients homogenously and selection of crop pattern. The management zone strategies are difficult to apply because of the synchronized physiological principles of the crop at the farm level. The dependence of these principles is based on the relationship among crop environment and crop growth and yield (Monzon et al. 2018).

Long-term effects on crop production are achieved through the implementation of precision agriculture technology through an increase in yield of crop applying equal input amount, enhanced soil N use efficiency and evaluating yield variations studied by Mintert et al. (2016). Another study presented by Zhang et al. (2002) emphasized the system of conceptualized approaches of PA to achieve higher efficiency through low inputs and sustain agriculture. This PA technology proved fruitful from other conventional techniques by including geographic information system (GIS), global positioning system (GPS), information processing, advanced computing and remote sensing (RS). Site-specific management in PA technology is the fundamental way of treating a site instead of applying inputs like pesticides, herbicides and fertilizers. Based on the spatio-temporal variation for a specific zone, crop inputs are applied by various technologies aimed by PA to achieve a high yield in each of the crop zones. The soil fertility and yield of the crop are improved traditionally by the application of various fertilizers over the field (Singh et al. 2016). Because of this reason, nitrogen fertilizer was found as one of the primary elements and a key factor surviving during the growing period of a crop and maximum crop production based on the various conducted experiments. Cui et al. (2008) reported several rates of N fertilizer when applied to different regions with less efficiency of N fertilizer usage because of the repeatedly or excess application of N fertilizer on winter wheat. Hence, to achieve higher efficiency of N fertilizer use, precision nitrogen management strategies are very necessary to balance the N requirement of a crop and its application over exhaustive agricultural land (Cao et al. 2016).

1.3 Precision Agriculture (PA) Approaches: Instruments and Methods

The present management practices for the growth and yield of grain cereals over the world for N fertilizer result in low or less intake efficiency of nitrogen fertilizer. Stamatiadis et al. (2018) studied that usually, only 33% of the fertilized nitrogen is utilized at the time of crop harvesting. However, the rest of 68% fertilized nitrogen is lost in the form of environmental contamination, formation of acidity in the soil, leaching and runoff of N fertilizer resulting in the economic losses of farmers. The considerable cause for this less efficiency of N fertilizer use is failing to create an equilibrium state among the application and the requirement of fertilizer to the crop. Additionally, neglecting the spatio-temporal variation of physiochemical soil parameters in the field before applying the N fertilizer causes less recovery of fertilizer at the time of crop harvesting. The use of knowledge of precision agriculture techniques for the N-management strategies resulted in the improvement of the yield of grains by 8–48% due to increased N use efficiency at the farm level (Xia et al. 2017). Hence, to achieve or improve the N use efficiency and overcome the losses at the farm level, knowledge of nitrogen management strategies is very important to implement. Some major methods and approaches that would be useful while determining the crop N requirement and crop N status at a different level of crop cereal growth are discussed in the next section.

1.4 Positioning System Development for PA

The concept of PA is based on site-specific assessment and management of variation in agronomic resources and inputs (Tayari et al. 2015). Realization of PA is only possible through collection of data pertaining to various parts of the field. Positioning systems are the only means that can be applied to fulfil the spatial data needs of PA. USA's global positioning system (GPS), Russia's global navigation satellite system (GLONASS) and Europe's global navigation satellite system (GNSS) are the three most known positioning systems. However, GPS is most widely and extensively used in application to agriculture. GPS receivers receive signals from the satellites and in turn convert them into location, speed and time (Tayari et al. 2015). Information acquired with the help of GPS receivers in integration with other devices can be used for developing ground truth maps of soil and crop properties, for prescription of fertilizers and pesticides according to the soil properties and condition, for optimization of tillage operations according to variable conditions across the field and for monitoring and recording of crop yield data (Dixit et al. 2014; Farid et al. 2016).

1.5 Guidance Systems for Agricultural Machinery

Guidance of agricultural machinery for application of agronomic inputs benefits mainly in two ways, i.e. savings of agronomic inputs and fuel due to lessened overlapping of machinery operations (Balafoutis et al. 2017). The extent to which GPS-based machinery guidance reduces overlapping is depicted in Fig. 4. This reduced

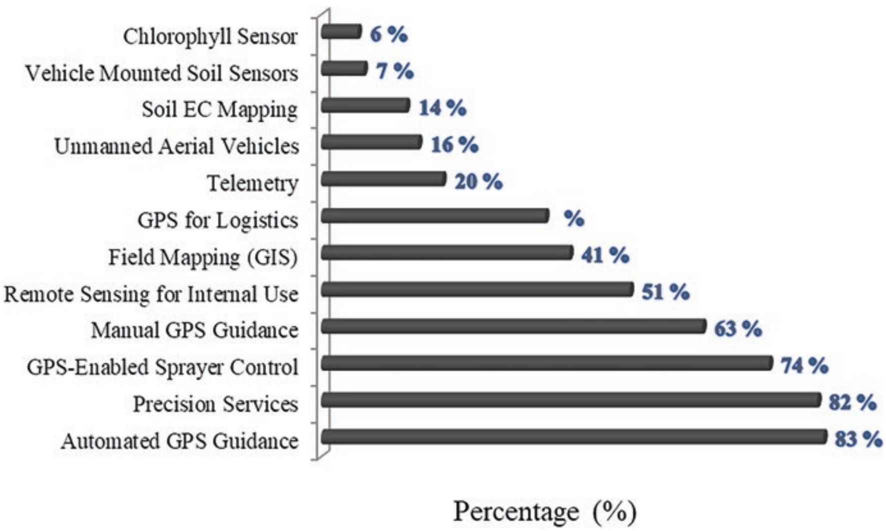

Fig. 4 Various precision agriculture technologies

overlapping results in many benefits like straight crop rows, fuel saving, time saving, labour saving, ability to work at night and input saving. Agricultural machinery guidance systems have been tried and tested all over the world in various conditions for different crops, and the results show that in addition to considerable environmental benefits, these technologies can yield cost savings of up to 56 dollars per hectare on average.

1.6 Nitrogen Management Practices in Precision Agriculture (PA)

To encounter the demand for crop production, useful and necessary nutrients must be provided to the crop which enhances the efficiency and growth of a crop. The use of these necessary inputs in the form of nutrients creates a dynamic equilibrium state among the requirement and the uptake of chemical fertilizer by a crop to boost up the fertilizer efficiency. Traditionally, the productivity of soil and crop is being enhanced by the use of various chemical fertilizers. Hence, based on the various conducted experiments all over the world, nitrogen fertilizer was found as one of the primary elements and a key factor during the growing period of a crop (Wang et al. 2019a) reported nitrogen as a major nutrient to look after the plant growth processes and yield a crop, synchronizing the physical, chemical and biological processes arising in the tissues of plants. Nitrogen fertilizer is an essential element for plant bodies that blends their chlorophyll content and conciliate the enzymes, vitamins and other amino acids (Irfan et al. 2018). Optimum rates of N fertilizer reduce disease risk over the plant and improves the chlorophyll contents. However, excess and lower application of nitrogen favours badly for crop growth and might result in premature plant growth because of diseases and abnormal flowering of plants (Salman et al. 2012).

It was reported by Diacono et al. (2013) that N fertilizer is the most fruitful input to apply on wheat for its better production. At the farm level, every farmer tends to supply a higher concentration of N fertilizer over the crop because of the myths developed due to conventional farming practices. Because of this reason, crop growth and yield instead of improving get lowered due to the formation of weeds around the crops (Wang et al. 2019b). Moreover, an excess the concentration of N fertilizer at field conditions causes problems such as denitrification due to soil acidity, leaching or runoff (Qu et al. 2014). To overcome the loss of potential of N fertilizer, precision management techniques should be applied at the farm level. Moreover, the type or amount of input should be applied in the field at the right time according to spatial variabilities and the requirements of the respective crops. The field spatial variability mainly depends upon the spatial distribution of all types of soil physical and chemical parameters of the whole field. The knowledge of these physiochemical parameters to take into account is very significant while dealing with the site-specific management of every crop input (Yao et al.

2014). Hence, to improve soil efficiency and overcome the lower or excessive application of N fertilizer, farmers should move to the recommendations of precision agriculture techniques and focus the soil requirement patterns of N fertilizer at the field level (Xiao et al. 2019).

1.7 Remote Sensing in Precision Agriculture

The technique “remote sensing” is used to sense and organize the objects present on the earth’s surface carrying useful information without any physical contact with these objects through satellites escalated and aircraft-based perceiving technologies. Remote sensing technique had been widely applied in the field of agriculture by Teke and Sakarya (2013). Nevavuori et al. (2019) applied the study of remote sensing techniques to identify the crop yield and the changing stages of growing crop biomass. Sprintsin and Alchanatis (2013) determined the spatial distribution of available crop nutrients in the soil. The primary factor for remote sensing measurement is the emitted electromagnetic radiations from the satellite that bounce back from agricultural land providing information. Mulla (2012) characterized the approach of remote sensing in precision agriculture based on sensors. This approach also punches the collection of information through aerial, satellites and near to ground podiums. Additionally, evolution in the form of proximal sensing is developed in remote sensing that involves the use of handheld or mounted sensors close to the surface of the earth. Another form of remote sensing is thermal sensing that implements the determination of water stress in crop canopies and the existing evapotranspiration coefficients during the crop growing stages (Kullberg et al. 2017). This water stress being measured through the emitted radiations from canopy and temperature of leaves. The reflected radiations from plants and absorbed radiation from plant pigments represented an inverse relation among them. Thus, 400–700 nm absorbed by plant chlorophyll, i.e. in the visible spectrum, but high leaf density and canopy indulge 700–1300 nm, the range of NIR for maximum reflectance of plants. Hence, various crop indices produced through the red to near-infrared ratio of spectrums are used to access plant attributes like plant N concentration, shoot biomass, etc. (Frels et al. 2018).

1.8 Nitrogen Management Using Satellite Remote Sensing

Several remote sensing imagery satellites for agriculture had been launched previously having diverse ranges of spectral resolution and bands. The obtained image information from revolving remote sensing satellites solely depends upon the image resolution, frequency return of the spatial images and the elevation of the revolving satellite. The pixel resolution governs the similarity of characteristics of crop and available soil nutrients. The homogeneousness of these characteristics of any particular area may vary with the increase or decrease of the spatial resolution. Temporal variations in the physiochemical characteristics of soil can be accessed through return frequency (Mulla 2012). Reyes et al. (2019) used Landsat imagery for the measurement of N, P and K concentration and electrical conductivity in the soil matter. Similarly, various other satellites are also used for image collection in agricultural fields such as IKONOS, QuickBird (Isabel and Francisca 2013), RapidEye (Sang et al. 2014) and GeoEye (Johansen et al. 2018). The IKONOS came into existence in September 1999 operating at 5 days' return frequency to collect 3.28-m image resolution. QuickBird imagery satellite was launched in October 2001 working at a return frequency of 3.5 days having 65–262-cm image resolution. IKONOS and QuickBird satellite images were used to identify the nitrogen deficiencies in wheat crops. RapidEye was launched in August 2008, at a spectral resolution of 65 cm with a return frequency of 1 day. The RapidEye imagery satellite works on the blue, green, red, red edge and NIR spectral band to provide chlorophyll images of leaves. GeoEye, in contrast with RapidEye, has no major differences working on the blue, red, green and near-infrared spectral bands. The only difference has a return frequency near 3 days for the spectral resolution of 46–183 cm. However, the major estimating crop index to identify the N concentration of crop and its decision-making, crop yield ornaments and crop shoot biomass is the "normalized difference vegetation index" (NDVI) (Wang et al. 2019a). Lai et al. (2018) applied empirical models to analyse the wheat yield through time-integrated Landsat NDVI. The relation of NDVI as expressed by Lai et al. (2018) is given as follows:

$$\mathrm{NDVI} = {\lambda_{NIR} - \lambda_{\mathrm{R}}} \Big/ {\lambda_{NIR} + \lambda_{\mathrm{R}}} \tag{1}$$

where λ_{NIR} and λ_{R} represent the wavelength of near-infrared and red rays, respectively.

The only restriction to evaluate the NDVI value of a given plant is the low canopy density that alters the chlorophyll amount at the highly denser area of a particular crop. However, apart from NDVI, many other indices are available in the context of precision agriculture to access the crop attributes in remote sensing. These different crop indices are normalized green index (NGI), ratio vegetation index (RVI), normalized red index (NRI), relative normalized difference vegetation index (RNDVI), difference vegetation index (DVI), green difference vegetation index (GDVI), relative green vegetation index (RGVI) and green ratio vegetation index (GRVI). Therefore, applying the science of remote sensing for field management in precision agriculture reduced much of the field problems. Hence, the application of remote sensing for precision nitrogen management is useful in many ways during cloud-free days. However, certain limitations still exist in remote sensing other than cloud coverings including the correction of images obtained interrupted by the atmosphere, calibration of sensors, choosing high-resolution sensors and analysing the images correctly at different NADIR angles.

1.9 Transmuting Remote Sensing as Proximal Remote Sensing

The SPAD (soil-plant analysis development) meter was used initially which leads to the conversion of remote sensing to proximal sensing. This SPAD meter determines the chlorophyll contents of leaves for upbringing better N decisions over the agricultural field. After serious contemplation, advances in proximal sensing are applied in fields to determine crop attributes along with the N deficit areas in the field. Proximal sensing is the technique of implementing mounted sensors of tractor or handheld canopy sensors working near the earth's surface. The prime purpose of precision crop management to apply the right inputs at the right time on the right place in the right way can be achieved through these proximal sensors. Marino and Alvino (2014) optimized the proximal sensing approach on drip-irrigated tomato fields. The approach utilized three vegetation indices to determine the spatial variability and homogeneity of the crop area. Li et al. (2019) utilized digital proximal soil mapping for nutrient management of irrigated sugarcane crops to boost up the yield productivity and for better nutrient decision-making. Moreover, efficiency comparison among γ-ray and electromagnetic data proved γ-ray results to be more effective and useful for soil nutrient management.

1.10 Precision N Management Using Proximal Sensing

In the days of the modern age, farmers are still looking to find the best means to decide and apply appropriate N decision-making to boost their profit at the time of harvesting. The countries that are going through the developing phase and relying on their economy completely on agriculture lack the use of new technologies and approaches (Mahmood et al. 2013; Say et al. 2018). The application of the precision agriculture approach helped various countries to save fertilizer expenses and environmental contamination. The optimum N fertilizer supply depends upon the equilibrium between demand and supply of N fertilizer at the field level. However, it becomes very difficult to create supply and demand balance due to arising limitations at the field level. Biologically, the optimum N fertilizer rate depends upon the type and the quality and quantity of the product used for N supply to the field. The better the quality and quantity of the N supply, the better will the crop yield obtain (Galindo et al. 2019). Bramley et al. (2013) derived a crop response curve based on several N rate experiments to decide optimal N fertilizer application at the farm level. The optimal N fertilizer application is beneficial to farmers economically and reduces the leaching of N fertilizer as nitrate NO_3.

The topmost layer of soil having nutrients may face variations, both spatially and temporally. These variations arise in two different phases, i.e. during a single or changing cropping patterns and among different fields or in a single field. Because of this complication, it is very necessary to utilize a precision agriculture approach instead of conventional practices that do not account for the optimal N supply to the fields. For this purpose, different arising temporal and spatial variabilities can be diagnosed using crop sensors and other mounted implements. Ali et al. (2017) reported the adaptation of proximal sensing as a valuable solution to gather field data non-destructively from the past few years. The proximal crop sensors have been adopted to site-specific nutritional management and to decide N supply by many researchers (Cao et al. 2015; Zhou et al. 2017).

The conventional application of N fertilizer above the crop demand is a common issue because of high expectations to achieve higher yields and less N fertilizer expenses. Moreover, fluctuations in the price rates of fertilizer become out of range for farmers during the crop growing seasons. These constraints impulse farmers to apply fertilizer conventionally rather than considering the crop fertilizer requirement during its growing season. The N fertilizer is the essential nutrient required to maximize crop growth by influencing the photosynthetic processes over the leaves. Hence, improved crop growth and yield of any crop is accomplished depending on the optimal application of N fertilizer over the field (Cui et al. 2010).

The concentration of N fertilizer to be applied over the agricultural field should not exceed or decrease the crop demands at any particular time during the crop season. The higher the N supply rate, the lower the optimization of N fertilizer, and more soil and the environment get contaminated. However, less supply of N fertilizer slows down the leaf growth and vegetation processes of crops during the growing season (Ghasemi-Aghbolaghi and Sepaskhah 2018; Shahrokhnia and Sepaskhah 2016). Another source to improve nitrogen use efficiency (NUE) is the split application of nitrogen fertilizer to synchronize the crop N demand and availability in the soil (Wang et al. 2016). The adoption of VRA in the previous decade increased because of its beneficial aspects of crop yield and return over N fertilizer cost. Evangelou et al. (2020) when applying variable rate application (VRA) on maize improved the agronomic NUE and amplified the N fertilizer return cost based on the conducted experiments.

1.11 Precision N Management Using Active Canopy Sensors (ACSs)

Cui et al. (2010) established a nitrogen management strategy during the in-season growth period of winter wheat. The strategy was developed in the context of over-fertilization mainly to boost crop yield with minimum environmental hazards. However, the soil N test of root zones is often not available to most of the farmers, and being a time-consuming method makes it difficult and challenging for farmers to apply (Cui et al. 2008). Thereby, the use of active canopy sensors (ACSs) to maximize crop yield has become a new revolution in precision agriculture. The ACS mainly focuses to prepare guidelines of in-season N management for use non-destructively. Many researchers (Cao et al. 2016; Xia et al. 2015; Yao et al. 2012) used ACS to make N supply decisions for optimum crop yields and in-season N management. Mostly, two active canopy sensors (ACSs) are accessible to look after the issue of N supply decisions at field scale, i.e. Crop Circle™ and Green Seeker™.

1.12 Application of Green Seeker (GS) for Precision N Management

Trimble Navigation Limited (Sunnyvale, California, USA) initially established the Green Seeker sensor. The sensor assists in N supply decisions on different crops to calculate two of the vegetation indices, i.e. NDVIs (normalized difference vegetation indices) and RVIs (ratio vegetation indices). The optimal working of the Green Seeker (GS) focuses on red and near-infrared wavebands ranging from 655 nm to 775 nm. Yao et al. (2014) studied the suitability of ACS at on-farm conditions having their light source. Additionally, another index is known as the response index (RI) to calculate the nitrogen requirements on the field scale. The relation of RI is expressed as follows:

$$RI = \frac{\mathrm{NDVI}_{NRS}}{\mathrm{NDVI}_{\mathrm{NNRS}}} \tag{2}$$

where $\mathrm{NDVI}_{\mathrm{NRS}}$ states NDVI of N-enriched strip and $\mathrm{NDVI}_{\mathrm{NNRS}}$ states NDVI of the non-N-enriched strip. Colaço and Bramley (2018) determined the N requirement and NUE of the applied fertilizer by the application of the response index. The Green Seeker sensor not only assists in N supply decision-making but also reduced the N fertilizer application over a particular area. Butchee et al. (2011) reported 49.91 lbs N/ha less use of N fertilizer using Green Seeker and increased the N rate to 40% above the farmer practices.

1.13 Application of Crop Circle (CC) Precision N Management

The Crop Circle ACS-470 was established by Holland Scientific Incorporation (Nebraska, USA). The crop circle is a handheld sensor utilized in precision N management to maximize crop yield and growth. Singh and Ali (2020) reported a crop circle sensor used to improve the nitrogen use efficiency with less N supply for cereal crops. The crop circle consists of blue (430–470 nm), red (530–570 nm), red edge (630–680 nm) and near-infrared (720–740 nm) spectral bands to evaluate various vegetation indices. However, many researchers reported the use of crop circle provided an improved assessment of crop N status and N decision-making as compared to the Green Seeker canopy sensor (Amaral et al. 2014; Cao et al. 2017; Erdle et al. 2011). Therefore, these active canopy sensors were used by farmers using precision agriculture to maximize crop yield and optimize crop profit at the end of a crop period.

1.14 Environmental Impacts of PA

Potential environmental benefits of PA technologies have been discussed since the use of the first GPS device on an agricultural field. Environmental benefits of adoption of PA technologies have already been mentioned in preceding sections but the ever-augmenting importance of this matter demands a deeper exploration. PA through prescription mapping and VR application reduces the use of all plant production and protection agrochemicals. This controlled and need-based application results in reduced mass loading of agrochemicals into agricultural effluents. Consequently, these effluents can be treated and managed effectively and economically. Furthermore, groundwater pollution that results from leach down of agrichemicals is also minimized. Earlier studies have also shown how limited application of plant protection chemicals can reduce the rate of development of resistance in organisms against pesticides. Environmental benefits of PA have been nominated by agriculturists and estimated by the researchers. But most of these studies relied on indirect and qualitative measurements to evaluate the environmental impact of PA techniques. Considering the rising concern of agriculturists about the environmental impact of agronomic practices, quantitative and direct measurements are necessitated. This study is an effort to review the work that has been done. Agronomic environmental impact depends on the type and quantity of chemicals used. Table 1 summarizes the environmental risks of various nutrients and soil organic matter (OM). It is evident from Table 1 that excessive use of nitrogen-containing fertilizers among other nutrients presents the biggest threat to the environment.

Table 1 Environmental risks of agro-nutrients and soil organic matter (OM)

Phenomenon	N	P	K	S	OM
Denitrification	Yes				
Eutrophication	Yes	Yes			
Leaching	Yes				
Precipitation	Yes	Yes	Yes		
Runoff	Yes	Yes			Yes
Saltation			Yes		
Volatilization	Yes				

Source: (Bongiovanni and Lowenberg-DeBoer 2004)

2 Conclusions

The contribution of agriculture towards the GDP of most of the countries in the world is considered as the backbone of the economy. The temporal increase in population rate and the food demands is becoming a great challenge in this modern age of changing climate. Because of these challenges, the socio-economic condition of farmers in developing countries demands to optimize the knowledge of precision agriculture technologies to maximize crop yields with minimum application of crop inputs. However, conventional farming practices are unable to provide reasonable outcomes of the crop because of the unvarying fertilizer application over the crop. Several techniques and methods have been established all over the world to identify the spatial and temporal variabilities of the physiochemical properties of soil during crop growth stages. The site-specific N management is the principal method of precision farming. The more efficient inputs applied efficiently, the more will be the profit per unit area with less application of inputs through these sensors. These crop sensors providing instantaneous fertilizer rates at field scale considering soil nitrogen availability and crop growing patterns are one of the best examples to utilize the time-saving approach. Therefore, the use of these sensors at the agricultural land should be promoted and subsidized for the betterment of the agricultural system in underdeveloped countries.

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Part III
Policy Measures for Adaptation: Climate Resilient Agriculture

Irrigation Scheduling Under Crop Water Requirements: Simulation and Field Learning

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Abstract Effective water use depends on judicious application of irrigation at the right amount at the right time and with the right methods. Irrigation scheduling deliberates when to apply, how much to apply, and where to apply in the crop field. Especially, irrigation scheduling is the decision of when and how much water should be applied in field crops. Inefficient water use in poor nations resulted in water losses up to 25%. Inadequate levelled crops and unscheduled irrigation without taking into account the management allowable deficit (MAD) and potential soil

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_15

moisture deficit (PSMD), and without soil and meteorological requirements, could not provide the exact information of agricultural irrigation necessities. The calculation of crop water requirements and significantly improved water use efficiency may decrease the environmental consequences of watering and increase the resilience of agricultural production by conservative water use applications with proper measuring of soil moisture levels. In this chapter, the concepts of field capacity, management allowable deficit, potential soil moisture deficit, and permanent wilting point are expanded with descriptions. Under water-limiting circumstances, simulation modelling from decision support system for agrotechnology transfer (DSSAT) played a significant role in irrigation scheduling with estimation of possible evaporation. DSSAT determines daily crop water requirements (ETc) and irrigation scheduling based on read-in values with automatic applications based on soil water depletion. Conclusion of study strongly intervened modelling and measuring soil moisture with vital utility in irrigated agriculture and must be used in order to maximize the advantages of a limited irrigation distribution. Several strategies for better water management practices under current climate change scenarios provides irrigation opportunities to meet the water demands for all users in developing countries.

Keywords Water management · Irrigation scheduling · Soil moisture · Management allowed deficit (MAD) · Field capacity · PSMD · Permanent wilting point · DSSAT

1 Introduction

Some of the utmost important ecological resources, i.e., water, is getting alarmingly sparse. A quarter or more of the water applied inefficiently in developing nations especially Pakistan, India, Bangladesh, Bhutan, Sri Lanka, Somalia, etc. is wasted frequently. Investigating agronomic practices that consume less moisture and improve water use efficiency (WUE) is the current need of this decade because of the rapid decline in indigenous water resources (Dubale 2001). When the twin threats of demographic stress and global warming are increasingly testing the world's limited water resources, water deficit will become even more important (Chaves and Oliveira 2004; Usman et al. 2009; Hammad et al. 2010; Awais et al. 2017). Scientific advancements have rendered its feasibility to calculate the quantity of water needed for a field, apply water model equilibrium in the land, and assess the effects of water deficiency on production with fiscal advantages (Rosero et al. 2020). Owing to the large administration and transportation inefficiencies in arid and semiarid locations especially in developing countries, improved agricultural water usage is urgently needed there (Hoekstra and Chapagain 2006; Usman et al. 2010; Jabran et al. 2017a, b; Fahad et al. 2015a, b, 2018a, b, 2019a, b, 2020, 2021a, b, c, d, e, f, 2022a, b; Fakhre et al. 2021; Farah et al. 2020; Farhana et al. 2020; Farhat et al. 2020; Haider et al. 2021; Hamza et al. 2021; Haoliang et al. 2022). Thus, arranging irrigations can have a significant effect. For maximum production, WUE can be improved with utilizing deficit or managed deficit in irrigation scheduling (Bekele and Tilahun 2007). The schedule and amount of water to administer and promote effective water use are decided by the irrigated agriculture sector. By conserving water, appropriate irrigation scheduling might lessen the effects of irrigation on the environment and increase the viability of irrigation systems (Khan et al. 2006). It is crucial to look for the factors that allow for the adoption of appropriate irrigation timing. This allows us to administer the precise quantity of water needed to achieve the desired water content. The fundamental goal of irrigation scheduling is to keep soil moisture levels closer to the soil surface in order to obtain the maximum beneficial supply of water for harvest output (Acevedo-Opazo et al. 2010; Hammad et al. 2017; Zia et al. 2017; Ahmad et al. 2019; Ali et al. 2022; Bukhari et al. 2021; Emre et al. 2021; Fahad and Bano 2012; Fahad et al. 2017, 2013, 2014a, b, 2016a, b, c, d).

Crop simulation models may be used to determine how much water is ought to be delivered when there is a shortage. Modern agricultural research is expected to be substituted alongside newer models to fulfil the present water and nutritional needs (Lal 2009; Saud et al. 2017a, b; Rasool et al. 2018; Hammad et al. 2018; Khan et al. 2018). Several professionals and scientists employ the Cropping System Model (CSM)-Crop Environment Resource Synthesis (CERES)-Maize to calculate watering plans for maize's prospective in diverse parts of the globe (Klocke et al. 2010). Various crop simulations, such as the CSM-CERES-Maize model (Soler et al. 2007; Rasool et al. 2020; Ali et al. 2020) can be used to estimate distinct geographical area and the specifics of meteorological seasons. Crop models may be used to predict everyday agricultural yields, growth, and productivity under various biotic and abiotic and agroclimatic circumstances using various agronomic managements (Kalra et al. 2008).

This chapter will cover notions such as field capacity (FC), potential soil moisture deficit (PSMD), management allowable deficiency, and permanent wilting point (PWP), as well as a few case analyses from around the globe that would demonstrate the value of moisture quantification and simulation techniques in irrigated agriculture.

Free water that enters, passes across, and exits the ground as a result of gravitation is known as gravitational water (Rahman et al. 2017). While moisture is kept in the pores and soil spaces among clay grains, as a thin coating of hydration by interfacial stress, plants primarily utilize capillary water (Chimner and Cooper 2004). Water, which is trapped onto earth granules as a result of electromolecular hydrostatic pressure, is significantly influenced by relative humidity (Appapillai 2018).

2 Field Capacity

Definitions of field capacity (FC) are as follows:

I. It is traditionally understood that the volume of water remaining after excessive irrigation has been drained out with downstream velocity (Gebrehiwot et al. 2015).

II. It is also stated that volumetric allocation of moisture contents in the top surface soil during submerged intrusion (with ponding depth less than 10 cm) becomes completely moistened at the final moment of intrusion and is subjected to the successive procedure of dewatering for 48 h without evapotranspiration or rain (Sample and Liu 2014).

3 Management Allowed Deficit (MAD)

The choice of MAD is required to decide when to irrigate. This management decides how much moisture content may be lost before irrigation. One of three methods exists for the MAD to be conveyed:

(i). Available water capacity (AWC) at root zone
(ii). Soil water deficit (SWD) in millimeters (mm)
(iii). Allowable soil moisture strain permitted soil moisture tension level

4 Permanent Wilting Point

The quantity of moisture level of a topsoil upon which signal crops cultivated are unable to recuperate if transferred in a humidified atmosphere is known as the permanent wilting point (PWP). Roots stop extracting moisture levels at PWP. The optimum moisture content at 1500 J/kg (or –15 psi) vacuum tension is generally regarded the permanent wilting point (Hausner and Dixon 2004).

5 Potential Soil Moisture Deficit (PSMD)

Potential soil moisture deficit (PSMD) is the difference among potential evapotranspiration (PET) and precipitation including watering. It aids in the calculation of water shortages in a method that can be continually used to demonstrate canopy development in reaction to water shortage (Szeicz and Long 1969). Several researchers have utilized PSMD to examine how irrigation affects the production of crops including grains of faba beans, maize, and potatoes (Ferreyra et al. 1997).

6 Typical Soil Moisture Characteristics

Numerous researches that look at the hydration properties of different soils depending on the surface are accessible in the literature. Figure 1 displays the soil moisture volume at field capacity with enduring wilting point, while Fig. 2 also includes certain additional soil properties including bulk density and available moisture levels, which provide these data on a weight scale. The total accessible water (TAW)

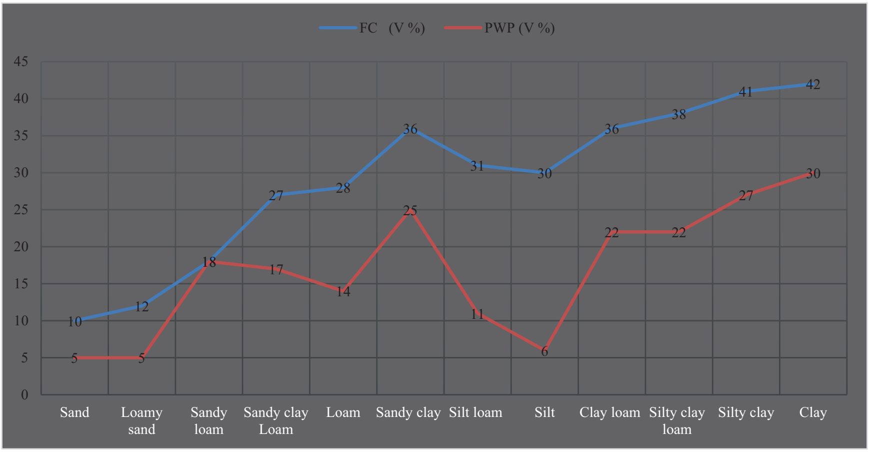

Fig. 1 Plant wilting point at permanent level on field capacity with different soil textures (Devices 2006)

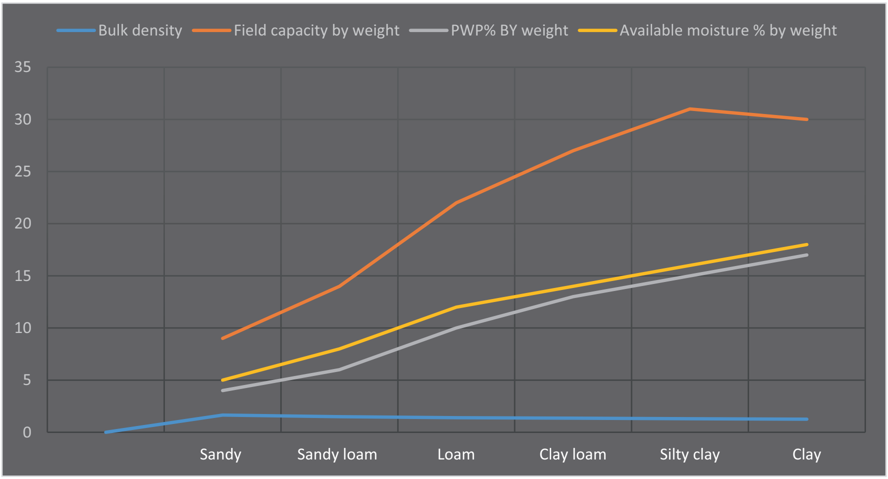

Fig. 2 Soil moisture characteristics of different soils on the basis of their physical analysis (Choudhary 2008)

variation in regard to soil characteristics is shown by the connection among FC and PWP for different soil conditions (Fig. 3).

7 Soil Moisture Content (%)

Soil moisture is the amount of water content (%) of the soil in terms of volume or weight. Some methods of soil moisture content (%) measurement are as follows.

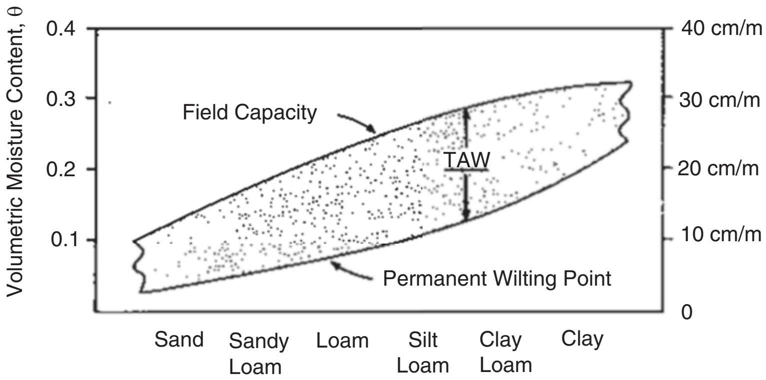

Fig. 3 Field capacity, PWP, and holding capacity of available soil moisture contents of different soils (Walker 1987)

8 Soil Moisture Sensors

A soil moisture device is a device that processes soil moisture through its sensor. Radars assimilated into the irrigation scheme provide exact supply and distribution with efficiency. Such sensors help shrink or enhance irrigation for maximum plant growth and development (Fig. 4).

9 Tensiometer

Tensiometers measure the soil moisture contents with entities of negative pressure that is known as tension. Tension is a measurement of force in different plant roots which exert to extract water from soil (Fig. 5).

10 Neutron Moisture Meter

A neutron soil moisture gauge is a moisture meter using scattering of neutron. This probing meter is frequently used to measure the water contents (%) in the soil and rocks. This is a nondestructive sensitive method that detects moisture in the bulk of proposed soils throughout the specimen instead of top layers (Fig. 6).

11 Determining the Amount of Water for Irrigation

11.1 Performance Indicators

Annual relative irrigation supply (ARIS) was introduced by Malano and Burton (2001) as

Fig. 4 Soil moisture meter SM-150

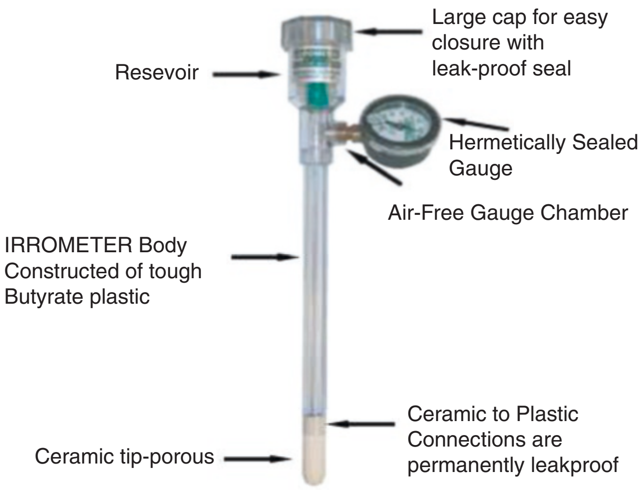

Fig. 5 Tensiometer

Fig. 6 Neutron moisture meter

$$\text{ARIS} = \frac{\text{Annual volume of irrigation water inflow}}{\text{yearly crop irrigation demand}} \tag{1}$$

Usually, ARIS lets the characterization of inceptions to indicate irrigation shortage valid for different rainfall conditions.

$$\text{Whereas} \quad IWP = \frac{\text{Increase in value of } \textit{product}\text{ion } \textit{due} \text{ to irrigation}}{\text{Volume of irrigation water inflow}} \left(\notin / m^3 \right) \tag{2}$$

IWP is the alteration of traditional water productivity calculated as the difference between actual yield under irrigation and rain-fed output.

Irrigation scheduling is calculated through the *LORMOD* technique by using different inputs of crop evapotranspiration (ET) indicators:

A. Traditional Kcb values can be obtained through crop ET from Allen et al. (1998) methods.
B. Actual Kc act values can be determined through METRIC ET tools.
C. The Kc envelope curve can be obtained from plotting through the Kc act.

Above all three substitutes deliver a conventional irrigation scheme adapted to local/regional conditions. Many other indicators used in Pakistan and other countries for possible estimation of water use efficiency are as follows.

11.2 Recovery Cost Ratio (RCR)

The common term "Abiana" is the cost of recovery collected from farmers to the distribution cost.

11.3 Monetary Delivery Efficiency (MDE)

This is an operational and maintenance (O & M) cost for delivery efficiency at distribution cost (D).

11.4 Relative Water Cost (RWC)

This is total irrigation cost (*I*) and total production cost (*P*) from the irrigation department that shows the share of irrigation cost on the total production cost of a certain crop. Production cost includes all inputs like irrigation, tillage, seed, manuring, pesticide, and labor cost.

11.5 Comparative Farm Irrigation (CFI) Cost

This ratio is between on-farm irrigation costs and total irrigation cost. If the RFI is high, it means there is potential for the reduction of on-farm irrigation cost.

11.6 Benefit and Cost Ratio (BCR)

BCR is the ratio between irrigation benefits and irrigation costs.

11.7 Delivery Act Ratio (DAR)

The ratio between observed discharge and target discharge (outlet).

11.8 Permanent Wilting Point (PWP)

This term links to the limit of available water. This moisture situation restricts the absorption of water by the plants and results in wilting.

$$\text{AC in volume\%} = \text{TP} - \text{FC} \tag{3}$$

11.9 At Sampled Moisture Content Before PWP

Although a coherent soil sample is collected, it is typically challenging to monitor PWP. Preparing agriculture at PWP may also endanger the harvest because it is impossible to guarantee that the crop will return to regular development once it reaches PWP. As a result, watering needs to be used well before moisture content gets to the PWP. The technique for estimating hydration shortage at the root zone may be carried out by taking into account the genuine moisture levels estimated on the day of watering based on the soil sampling results obtained before the PWP.

Example
Calculating available moisture prior to PWP = 10.0% by weight

$$\begin{aligned}\text{Moisture shortage} &= (\text{FC} - \text{real moisture})\,\text{BD} \times \text{depth} \\ &= (25.0 - 10.0)1.6 \times 60.0 \\ &= 14.40\,\text{cm}\end{aligned} \tag{4}$$

12 Running Allowed Deficit (RAD)

In comparison to administering irrigation immediately at the observed moisture level, irrigation scheduling necessitates more scheduled irrigation events. By detecting a deficit in the perspective of a certain proportion of the total moist accessible, MAD enables watering at a period that is already specified. When the FC, PWP, and AM are established, watering may be used for a certain MAD together with consistent assessment, allowing the irrigator to determine hourly timing of watering significantly in advance of watering day. The accompanying scenario demonstrates this.

The hydration shortfall or water depth required in the surrounding soil may be calculated as follows, presuming MAD is 70% of the accessible moisture:

$$\begin{aligned} \text{Water requirement at the root zone} &= (\text{FC} - \text{PWP}) \times 70.0/100.0 \times \text{BD} \times \text{depth} \\ &= (25.0 - 10.0) \times 70.0/100.0 \times 1.60 \times 60.0 \\ &= 10.07\,\text{cm} \end{aligned} \tag{5}$$

12.1 Potential Soil Moisture Deficit (PSMD)

Potential soil moisture deficit (PSMD) is the gap of potential evaporation and transpiration (PET) versus precipitation (including watering) (French and Legg 1979).

13 Irrigation and Decision Support System for Agrotechnology (DSSAT) (Fig. 7)

13.1 Irrigation Management: DSSAT

If surface or groundwater is inadequate due to strategy and planning restrictions, water policy, or a drought, the best tool is the water model that can be used to help and regulate the best water scenario regarding the right application with the right environmental suitability.

13.2 Soil Water: DSSAT

Almost all DSSAT models shared the water balance subroutine in the soil. The soil water balance is calculated through the addition of irrigation and rainfall by deducting surface runoff, soil evaporation, plant transpiration, and drainage. Inside the soil

Fig. 7 An irrigation pivot watering a field (Source: DSSAT.net, the University of Georgia–Griffin Campus, USA)

column in the DSSAT software, the vertical drainage of soil water is redistributed when capillary rises up. In weather files, rainfall is delivered as a user input. Irrigation input files including types of irrigations, efficacy of water application, and amount of irrigation via experimental files would be prepared in the DSSAT program, while the SCS curve approach numbering is partitioned to infiltrate rainfall and surface runoff (Ritchie and Ritchie 1998).

13.3 Irrigation: DSSAT

The automatic management of irrigation can be quantified based on actual field histories and application proceeding events through the DSSAT software. Field entries consist of all stages from start to end and irrigation application methods, i.e., flood irrigation, sprinkler, or drip with amount of water applied. The irrigation productivity can be estimated on the basis of total supplied water requirements.

DSSAT-CSM runs simulated states and processed values on how to activate an irrigation schedule for various plant growth stages automatically. The automatic irrigation-triggered classes are soil moisture and evapotranspiration. Irrigation extents and scheduling can be calculated through a consumer-supplied fixed amount or deficit amount. Irrigation measuring may be limited by available water capacity (in all plant growth stages) and by a least duration between irrigation scheduling events. Automatic irrigation codes and their description in DSSAT4.8 are as follows (Table 1).

Table 1 DSSAT-CSM classes and values

Automatic irrigation code	Type of specification	Field schedule event specification	Irrigation trigger	Irrigation amount method (see table below)	Growth stage-dependent rules	Frequency	Available water limit
R	Field records	YRDOY	–	1	No	No	No
D	Field records	Days after planting	–	1	No	No	No
A	Automatic	–	Soil moisture thresholds	2	Yes	Yes	Yes
F	Automatic	–		3	Yes	Yes	Yes
P	Hybrid	YRDOY		4	Yes	Yes	Yes
W	Hybrid			5	Yes	Yes	Yes
E	Automatic	–	Rainfall and evapo-transpiration	6	Yes	Yes	Yes
T	Automatic	–		3	Yes	Yes	Yes

Sources: DSSAT 4.8

14 A Case Study of Stress Proportional to Field Capacity

Using Maize Hybrid (R-3333) as the quality seeds, a greenhouse experimentation was carried out in the Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan. Four weeks following seeding (four-leaf phase), three levels of dryness pressure were applied, highlighting the fact that moderate pressure created the largest amount of foliage to be produced, while extreme drought stress drastically decreased the leaflet surface. In addition, plants' fresh as well as dry masses of shoots and roots were considerably decreased by greater-intensity drought conditions at 50% of FC. On the other hand, a minor distress of 75% of FC led to an increase in plant elevation, root density, and shoot and root weight after oven-dried.

15 Improving Water Use Efficiency in Maize Crop Through Modelling Tools

Provision of low irrigation and aggregate water demand have an influence on the sustainability of the groundwater resources for agriculture (Hesham and Fahad 2020; Ilyas et al. 2020; Khatun et al. 2021; Saud et al. 2013, 2014, 2017a, b, 2016, 2020, 2022a, b; Shah et al. 2013; Subhan et al. 2020; Tariq et al. 2018; Wajid et al. 2017). To meet the increasing requirement for foodstuffs from a growing population, agriculture production must be increased while utilizing less water. In this case, deficit irrigation may have a significant role in increasing WUE. Research shows that regulated deficit irrigation (RDI) saved water while sustaining productivity during specified periods of the corn planting period. RDI permits large water savings for agricultural crops. RDI has also aimed to conserve water by allowing different levels of MAD to have little effect on yields.

The experiment was carried out at the University of Agriculture, Faisalabad, to investigate the impact of various water constraint remedies on the yield of corn fodder. When the corn (CV Golden) harvest was planted in the meadow, the watering procedures were initiated. The Neutron probe was employed to evaluate the pace of soil dehydration in the root system as well as to plan tillers in accordance with the designated MAD levels.

The upper 201 mm of the soil's water table deficiency was used as the watering parameter. Water supply was administered whenever soil moisture reached 21% level (MAD of 31.0%) or 17.5% level (MAD of 60%). For the top 400 mm of the root zone, irrigation intensity was computed.

Treatment effects were determined to be meaningful at a 5% statistical level depending on ground experiment results with GLEAMS model simulation analyses. While T2 had the highest WUE due to greater water stressors of 61.0% MAD with reduced irrigation applications, the treatment with 31.0% MAD level had considerably greater output than that of the other regimens. Using the verified GLEAMS model, the comparative impacts of managing scenario calculations revealed that maintaining soil moisture between 30% and 90% of the accessible water had the best WUE.

16 Maize Crop Modelling by Using CSM-CERES Models with Irrigation Application in Semiarid Conditions of Punjab, Pakistan

Research was carried out in semiarid circumstances in Punjab to assess the simulated CSM-CERES-Maize model for modelling of maize development and production following different irrigation regimes (Pakistan). During two fall seasons, field investigations at the University of Agriculture Faisalabad were done on two maize genotypes (Monsanto-919 and Pioneer-30Y87), and experimental data from those studies were utilized to run the model.

At varying phases of their vegetative and fertile development, both corn cultivars were subjected to varied watering practices.

Treatment at 25 mm PSMD was cast off since it produced the maximum output and yielded elements for two hybrids. The calibration indicated that the model performed quite well. For Monsanto-919 and Pioneer-30Y87, respectively, the model demonstrated variability of 1.1% to 10.20% and –4.30% to 6.4% in total dry matter and –8.50% to 24.30% and –15.80% to 27.70% in grain yield for various irrigation regimes. Everyday simulation of entire dried material performed well as well, with d-statistics values in all treatments over 0.97. The findings demonstrated the usefulness of the CSM-CERES-Maize model in simulating irrigation of autumn-sown corn in semiarid settings in Punjab.

17 Conclusion

The conclusion drawn from the explanation above is that measuring soil moisture is essential for planning irrigation schedules. In developing nations, experiments should be planned to determine the best ways to manage any existing water deficits and prospective moisture deficit soils. Results optimize the water use efficiency with high yield and sustainable development with exact methods and scheduling.

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Nutrient Management Under Changing Climate

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Abstract Food security is an emerging problem for the world. The different anthropogenic endeavors including the emission of toxic gasses, urbanization, and land deterioration are the major issues that enhance the problem of climate change. Climatic variability has caused different environmental stresses on the productivity of agriculture. Macro- and micronutrients have crucial importance in the different metabolic activities of plants. The plant cannot fulfill its life cycle without complete essential nutrients. The availability of essential nutrients is enormously affected by global warming because global warming affects different natural resources, viz., uneven distribution of rainfall, increasing annual temperature, and melting of glassier. The different abiotic stresses reduced the agricultural efficiency by 50–70%. The nutrient dynamic is also affected by climatic variability and reduces the plant defense mechanism against different diseases. To cope with the problem of climatic variability and enhance nutrient availability, different management practices have been made to reduce the losses and fixation of mineral nutrients. The role of mineral nutrients in different metabolic activities of plants and management of different macro- and micronutrient nutrients under the scenario of climatic variability have been the focus of this chapter. Split application of fertilizers, use of inhibitors, water conservation, and use of different organic amendments are enhancing the nutrient availability under climatic variability. In this chapter, the contexts about the availability of mineral nutrients and modern techniques of nutrient management to manage the problem of climatic variability are comprehensively illustrated.

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_16

Keyword Climatic variability · Abiotic stress · Agro ecosystem · Nutrient management

1 Introduction

Food security is a major problem of the world because the population of the world is increasing very rapidly. According to FAO, 33% growth is projected in the next 30 years and it is predicted that the total public community of the world will be around 9.6 billion by 2050. Requirement for food also increased in addition to the rapid growth of the human community. Food security is greatly related to future climatic circumstances (Burritt 2019; Hashmi et al. 2020; Shahid et al. 2020; Zamin et al. 2020; Hussain et al. 2020). Cultivated land under the agriculture sector has declined due to urbanization and deforestation (Mara 2012). The reduction in agricultural land inclusive of urbanization, deforestation, and burning of fossil fuel has caused pessimistic effects on climatic conditions. Consequently, different abiotic stresses are emerging and causing destructive effects on agriculture productivity. It also deteriorates the different correlations among ecosystems. The negative effects of climate change also exacerbate various factors such as decline of pollinating insects, increase of water shortages and ground-level ozone concentrations, and reduction of fishing levels. As a result, it is critical to evaluate the destructive effects of climate variability on the agriculture sector.

Global warming is a contextual different environmental stress in the world (Gray and Brady 2016). The agriculture sector has also faced various environmental changes in recent decades. It is predicted that these climatic changes are anticipated to intensify, and their frequency of happening is projected to rise. The climatic variability will cause more severe destructive effects on the agriculture sector if mitigation and adaptation techniques are not implemented (Fanzo et al. 2018; Shahzad et al. 2018; Wang et al. 2019; Fahad et al. 2019; Shah et al. 2019). As a result, indicated by a persistent intensification of agricultural systems, climate variability will represent a vast dispute to the agriculture sector and not delivering adequate healthy meals in the coming decades (Pretty et al. 2018).

Climate variability influenced the plant growth in different ways. Plant development and productivity are significantly enhanced by increasing the photosynthesis and water usage efficiency is frequently improved because of CO_2 (Amin et al. 2018a, b; Rahman et al. 2018; Li et al. 2018a; Ahmad et al. 2019; Akram et al. 2019; Sabagh et al. 2019; Danish et al. 2019; Iqbal et al. 2019; Khan et al. 2019). However, greater development under CO_2 is counterbalanced by decreased grain quality (Dong et al. 2018a, b). The CO_2 alters the balance between metabolism of CO_2 and absorption of minerals (Nakandalage and Seneweera 2018).

1.1 Plant Nutrient Classification

It is believed that distinct chemical elements are needed by plants for their growth and various metabolic processes. The nutrient requirement of plants is similar to a human body, that is, a series of nutrients are required to fulfil the life cycle but some nutrients are required in large or small quantities on the basis of their role in different metabolic activities. The deficiency of one nutrient cannot be fulfilled by any other element and involved in different metabolic activities Ashraf et al. (2018). Essential nutrients for plants which are needed in huge amount to fulfill the requirement of metabolic activity are called macronutrient which is required in small quantity called micronutrient. Complete plant nutrition is required for better crop growth and yield. The nine mineral nutrients are classified into macronutrients as far as seven are characterized into micronutrients. Plants uptake these nutrients in different forms, viz., organic and inorganic.

1.1.1 Macronutrients

Macronutrients are those nutrients which are required in large proportion as compared to other nutrients. These elements require more than 1000 ppm or 50 mg/kg of dry mass of plant. The macronutrients are classified into two further groups on the basis of their requirements. The primary and secondary macronutrients. The primary macronutrients are essential nutrients required in large quantity and plants cannot complete their life cycle in the absence of these nutrients. These nutrients are required for seed germination, basic growth, and root proliferation. Carbon, hydrogen, oxygen, nitrogen, phosphorus, and potassium are classified into primary macronutrients, while calcium, magnesium, and sulfur are categorized into secondary macronutrients because these nutrients are required in less quantity rather than primary macronutrients.

1.1.2 Micronutrients

Mineral nutrients which are required in less quantity are called micronutrients. The group is comprised of seven different essential nutrients which are required in low amounts. Recently, some trace and beneficial elements are also included in the category of micronutrients because these are essential and participate in the initiation of different metabolic activities. Molybdenum, manganese, chlorine, copper, boron, iron, and zinc are the main types of micronutrients, while sodium, silicon, and cadmium are ranked as beneficial (Barlow et al. 2015; Ali et al. 2018a, b; Hammad et al. 2018; Nasim et al. 2018a, b).

1.2 Role of Nutrients in Plant Development

Macro- and micronutrients have a vital importance in plant development and growth as well as preventing the plant from different diseases. Essential nutrients strengthen the internal defense mechanism of plants and decrease the severity of the disease. The capability of the soil to provide all the necessary elements for better crop development is called soil fertility (status of soil). Sixteen mineral nutrients are very crucial for agricultural productivity. Nitrogen deficiency affects the basic growth and activity of chlorophyll, as well as phosphorus, which plays a substantial role in the plant's physiological attributes and plant root proliferation and is a constituent part of the cell membrane. Potassium controls the osmoregulation of cells and enhances the resistance against abiotic stresses. The different micronutrient and beneficial elements are part of different metabolisms at the reproductive stage.

Nitrogen, phosphorus, and potassium improve the plant's resistance against diseases and increases the growth. Macronutrients play an essential part in plant health maintenance since they are essential for cognitive development and growth reproductive activities, metabolism, and immune system reflexes in individuals (Nakandalage and Seneweera 2018). Dietary nutrient deficiencies (sometimes known as "hidden hunger") are a worldwide problem that reduced the plant defense mechanism and decreased the plant yield (Haddad et al. 2015).

For optimal development and growth, plants require 16 mineral nutrients (Marschner 2011) (Table 1). These elements play a key role in the constituents of phospholipids, cellular metabolites, and nucleic acids, which are an integral part of essential amino acids in plants. They also aid in the formation of chlorophyll, redox processes, plasma membrane permeability, and cell osmotic pressure (Nakandalage and Seneweera 2018).

Plant development and productivity are also influenced by nutrient shortages, which limit the biosynthesis or transcription of critical energy uptake and metabolic processes. As a result, plants that have undergone vitamin deficiencies are often more vulnerable to abiotic stressors (Jin et al. 2009). To lessen their negative impacts on crop plant nutritional quality when grown in a changing environment, a detailed investigation is crucial to understand how these abiotic variables influence plant micronutrient regulation mechanisms.

2 Impacts of Changing Climatic Conditions on Agriculture

Variation in long-term weather condition that characterizes the world's area is indicative of global climate change. Short-term (everyday) change in temperature, wind, and/or rainfall in a certain location is referred to as "weather." It is concerned without changes in the climatic variability and the consequences of these changes in all the other parts of the planet. It could take tens, hundreds, or maybe millions of years for these changes to take place. However, human activity like manufacturing of

Table 1 Form, source, uptake mode and functions of 16 essential plant nutrients

Nutrient family	Nutrient	Percentage of plant	Form taken up by plants (ion)	Mode of uptake	Major functions in plants
Primary	Carbon	45	Carbon dioxide (CO_2), bicarbonate (HCO_3^-)	Open somates	Plant structures
	Oxygen	45	Water (H_2O)	Mass flow	Respiration, energy production, plant structures
	Hydrogen	6.0	Water (H_2O)	Mass flow	pH regulation, water retention, synthesis of carbohydrates
	Nitrogen	1.75	Nitrate (NO_3^-), ammonium (NH_4^+)	Mass flow	Protein/amino acids, chlorophyll, cell formation
	Phosphorus	0.25	Dihydrogen phosphate ($H_2PO_4^-$, HPO_4^{2-}), phosphate (PO_4^{3-})	Root interception	Cell formation, protein syntheses, fat and carbohydrate metabolism
	Potassium	1.5	Potassium ion (K+)	Mass flow	Water regulation, enzyme activity
Secondary	Calcium	0.50	Calcium ion (Ca^{2+})	Mass flow	Root permeability, enzyme activity
	Magnesium	0.20	Magnesium ion (Mg^{2+})	Mass flow	Chlorophyll, fat formation and metabolism
	Sulfur	0.03	Sulfate (SO_4^{2-})	Mass flow	Protein, amino acid, vitamin and oil formation
Micro	Chlorine	0.01	Chloride (Cl^-)	Root interception	Chlorophyll formation, enzyme activity, cellular development
	Iron	0.01	Iron ion (Fe^{2+}, Fe^{3+})	Root interception	Enzyme development and activity
	Zinc	0.002	Zinc ion (Zn^{2+})	Root interception	Enzyme activity
	Manganese	0.005	Manganese ion (Mn^{2+})	Root interception	Enzyme activity and pigmentation
	Boron	0.0001	Boric acid (H_3BO_3), borate (BO_3^{3-}), tetraborate (B_3O_7)	Root interception	Enzyme activity
	Copper	0.0001	Copper ion (Cu^{2+})	Mass flow	Enzyme activity
	Molybdenum	0.00001	Molybdenum ions ($HMoO^{4-}$, MoO_4^{2-})	Mass flow	Enzyme activity and nitrogen fixation in legumes

From Marschner (2011)

industry, urbanization, cutting of forest, and agriculture, on the other hand, has resulted in expanded land-use patterns, leading to greenhouse gas emission and a quick change in the degree of climate variability. The rise of global warming, uneven distribution in annual rainfall patterns, and more accumulation of CO_2 in the atmosphere are all part of climate change scenarios. The greenhouse effect caused the toxic impact on the agriculture sector in three processes. Firstly, increased CO_2 levels in the atmosphere can have a direct effect on plants and weed growth rates. Secondly, temperature, rainfall, and sunlight levels may be affected by CO_2-induced climate change, affecting plant and animal production. Finally, increasing sea levels may increase the loss of agriculture and a rise in the salinity of groundwater in coastal regions (Lu et al. 2011). This is mostly owing to agricultural intensification methods and specific plant breeding initiatives aimed at increasing production (Manners and van Etten 2018). Agricultural scientists endeavor to cope the problem of climate variability by evolving the modern techniques for crop management.

Most developing countries around the world have little understanding on the effects of climate variability and its role in the agriculture sector, which has a pessimistic impact on sustainable development (Kemausuor et al. 2011; Cakmak & Kutman 2018; Tariq et al. 2018). Climate change has fewer beneficial effects on human and ecological systems than negative effects (IPCC 2014a, b). The productivity and growth rate of agriculture in developing countries are particularly remarkable to climatic severe storms, droughts, and weather pattern increases in plant pests and diseases, due to the lack of adaptation skills and a higher vulnerability to climatic disasters including water stress, and climate variability enhanced the susceptibility of diseases and attack of pests on agricultural crops. Climate change is anticipated to intensify and increase the frequency of several forms of climate extremes globally (Cline 2007; Grover et al. 2015) (Fig. 1).

2.1 Drought Stress

Droughts and extreme weather have destructive consequences on the outputs of agricultural, as well as community welfare and food production. Not only are countries directly impacted by the terrible occurrence, but locations all around the world may see indirect effects such as decreased agricultural exports and rising in prices of different agricultural products (GFSP 2015; Puma et al. 2015). The productivity of the agriculture sector and cattle-feed shortage has been reported in Europe due to extremist weather conditions, which caused severe crop failures and cattle feed shortages across the continent (Hellin et al. 2014; Nasim et al. 2017; DW 2018; Nelson et al. 2009). Understanding the impact of past and contemporary climatic extremes on agricultural yields is critical for assuring and maximizing harvests in a changing climate. As a result of the excessive heat and cold, agricultural growers are already facing significant hurdles.

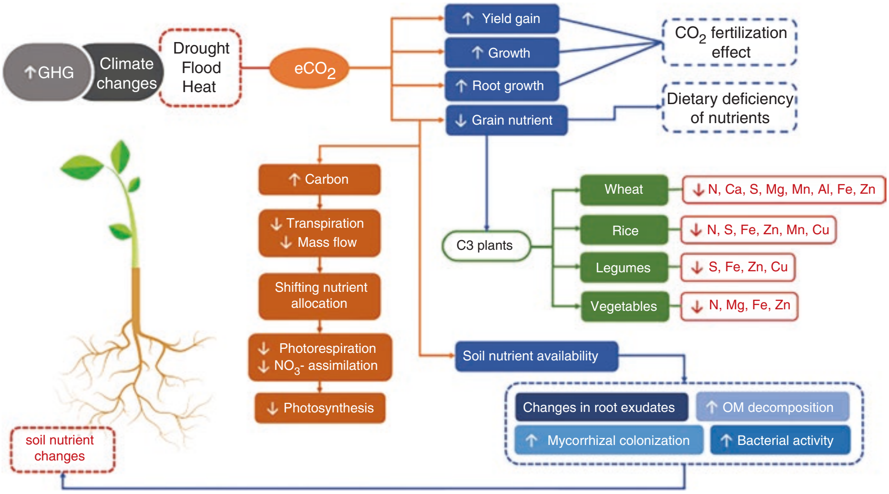

Fig. 1 Effect of climate change on soil nutrient

2.2 Temperature Stress

Temperature rises in the arid western mountainous areas may hasten the glacial process by harming our water supplies, which are vital to agriculture and energy generation in the country. As a result of a mix of natural and anthropogenic activities, these mountainous landscapes are already under significant stress. Subsequently, environmental deterioration in these locations is a constant process. Global warming (i.e., temperature rises and precipitation changes) is predicted to worsen the existing process of watershed degradation and jeopardize the long-term viability of Pakistan's mountainous and submountain regions, as well as downstream plains (Ullah 2017).

2.3 Soil Erosion

Soil erosion rates are influenced by climate change, which includes climatic impacts on plant biomass production, evapotranspiration rates, and soil bacterial activity. To adapt a new climatic regime, decomposition rate, surface soil strength, and land utilization are required. Changes in the erosive force or uneven distribution of rainfall have the most major effect of global warming on water erosion. According to research utilizing erosion simulation models, the response to rainfall intensity is substantially more sensitive than other climatic factors. Emission of toxic gases raised the air temperatures and accelerated the hydrological cycle, resulting in more intense and erosive downpour episodes.

2.4 Effect of Climate Change on Nutrient Dynamics

The anthropogenic variables have been the principal contributors to current global warming. As a result, large reductions in emissions of toxic gases are necessary with government agencies playing a key role (Myers et al. 2017). Global warming has increased by 1.0 °C from the preindustrial period and is anticipated to reach 1.5 °C by 2050 if present trends continue (IPCC 2018). The major driver of climate variability is due to greenhouse gas emissions into the atmosphere which has grown dramatically from the preindustrial period owing mostly to population expansion that is greater than ever. The high rate of emissions of toxic gases has resulted in CO_2 concentrations in the atmosphere that are unprecedented. This will induce more warming and worse climate system change raising the potential of severe and long-term consequences for ecosystems.

Furthermore, water scarcity affects the >2 billion population annually (Nezhadahmadi et al. 2013). Regular precipitation patterns are also a hotspot issue for the world and it is considered a key factor to enhance the drought condition globally. The decline in annual precipitation is also a threat to the agriculture sector because it reduces the nutrient uptake and movement of ions in the soil. Changes in soil moisture, an important component for nutrient availability because water potential gradient provides a substrate for plants to collect and transport nutrients, might have an influence on resources. Global warming caused negative effects on overall agricultural commodities that lead to the emerging problem of food security. The emerging population of the world, which is already prone to a shortage of food, is likely to bear the brunt of the consequences. As a result, in order to meet the demand for the global feed under the rapid change in climatic circumstances, it is necessary to provide nutritional quality and adequate food (Fischer et al. 2019).

Nutrient deficiency is a major issue in the world (Scheben et al. 2016). Macronutrient and micronutrient deficiency has received a lot of attention in recent decades especially in developing nations where many people rely on legumes and grains (Svoboda et al. 2015). Plant sensitivity to biotic and abiotic stressors is also affected by nutrient deficiency. However, plant genotype and availability of nutrients have big roles to ameliorate the toxic impact of climatic variability (Nakandalage and Seneweera 2018).

The water utilization and the availability of nutrients are enhanced because increased plant development is intimately linked to elevated CO_2 (Briat et al. 2015). Because of their function in crucial metabolic pathways, expanding this understanding to micronutrients is equally critical. It is critical to provide predictions of the plant mechanisms against global climatic variability. The present understanding of how climatic variations, particularly CO_2, affect them on the nutrient availability for crop development and their related physiological and molecular response mechanisms has been the focus of this chapter. Furthermore, the connection between the enrichment of CO_2 and the limited availability of mineral nutrients will be investigated. The last section will focus on reporting some of the measures that can be employed to maintain the availability of nutrients in future climatic variability.

2.5 Transformation in the Cropping Pattern and Sowing Date

Climatic dynamics had a significant impact on all aspects of human life, particularly crop cultivation, encountering environmental diseases, extreme heat or cold weather, and following hazards such as floods and drought, necessitating the infusion of coping infrastructure (IPCC et al. 2017). The twenty-first century is expected to see an increase in weather changes and a significant chance to developing countries' agricultural evaluation (IPCC 2014a, b). Weather change has the ability to affect agriculture in various ways, including crop quantity and quality in terms of growth rates, productivity, transpiration rates, photosynthesis, and moisture availability. Climate variability is likely to have a direct effect on the productivity of food globally. The variability in seasonal temperature caused the direct impact on the growing season of different crops and decline the annual yield (IPCC 2007).

Contrary to popular belief, farmers do not determine planting dates and cultivar warming times according to how the length of the season and average temperatures change as a result of global warming (Zhao et al. 2017). According to observational evidence, shifting degrees of risk avoidance, interactions between crop management and meteorological circumstances, and operational timeliness will make projections regarding future sowing dates and varietal choices exceedingly unreliable (Siebert and Ewert 2012; Eyshi Rezaei et al. 2017).

2.6 Unpredictable Rainfall Pattern and Effects on Growth and Yield

South Asia's net cereal production is anticipated to fall by 4–10% by the end of 2022 (Lal 2011). Under the climate change scenarios (SRES), the productivity of Pakistan's key staple food wheat and rice is anticipated to decline by 6–8% and 16–19%, respectively (IPCC 2014a, b). Climate change is wreaking havoc on Pakistan's agricultural output and farmer livelihoods. The farmer community is over the problem by adopting new modern techniques to sustainable agriculture. The adoptability of modern techniques is dependent upon three approaches, with the first phase being the awareness of changes in various climate change indicators such as seasonal temperature and rainfall. Farmers' intents and techniques of adaptation are significantly influenced by correct and timely observation (Deressa et al. 2011).

The exogenous constituent such as availability to natural resources and topography of the agricultural farm may have an impact on these beliefs. While erroneous views can contribute to disorder and increase farmers' disaster risk, proper perceptions can help them adapt. Correct perceptions can have a favorable impact on the farm's adaption process (Le Dang et al. 2014). Pakistan is ranked on the ninth position among the other countries of world which have faced the most destructive effect of climate variability, as reported by the World Risk Report. Due to the expected 2–3° rise in temperature by 2050, there will be considerable variability in rainfall (Kreft et al. 2016; Gorst et al. 2015).

Some of Pakistan's upper latitude regions (including Chitral) account for roughly 17% of the country's total land area. Heat stress and rising temperatures may help. Temperature rises may encourage crop growth and maturity. It enables for earlier winter crop planting and harvesting. Crop yields and crop area expansion are predicted to rise in these locations as temperatures rise. It would also be possible to do double cropping, taking full advantage of both the cold seasons. The species composition of forests may change. Fast-growing species are likely to supplant conifers. These places at higher latitudes are prone to frequent severe flooding. Land, agricultural properties, and livelihood assets are all severely harmed. Heat and water stress, particularly temperature rises, will diminish crop and livestock output in the lower latitudes due to climatic variability. Climate dangers including floods and droughts will affect the lower latitudes. Over the previous two decades, the frequency has grown in some locations, potentially as a consequence of climatic variability (Ullah 2017).

3 Nutrient Management Under Climatic Variability

The use of synthetic or natural fertilizers is crucial to sustainable nutrient management. When suitable practices are employed, this approach benefits both the farmer and the environment. Improving fertilizer efficiency should result in reduced application rates and costs, as well as a reduction in the quantity of nutrient wastage to the environment through flushing, volatilization, and denitrification. Nitrogen is the most damaging to the environment and the farmer's bottom line. The losses of nitrogen are very rapid compared to other macro- and micronutrients.

The ecological impact of carbon dioxide per molecule of gas and the oxidation of nitrite (N_2O) is the major effective agricultural greenhouse gas (GHG). In Manitoba, the accumulation of N_2O contributed to 66% of all agricultural GHG emissions (Canada 2009). The losses of nitrogenous fertilizer are through a number of procedures, which increase the chances of it being lost to the environment (Suzuki et al. 2014). Denitrification occurs when too much nitrogen fertilizer is administered, resulting in losses. This nutrient might also leak into groundwater or be released into the atmosphere through volatilization (Canada 2012).

The application of the 4R nutrient technique has the most significant results on the quantity of availability and losses of nutrient management. The crop utilizes just about half of the nitrogen provided in the year it is applied. The remaining nitrogen quantity rather than that which is utilized by the plant is lost through leaching and immobilization of nitrogen and ammonia from volatilization. The loses of nutrient, especially of nitrogen, is directly proportional to management practices. The application time, rate, source, and methods are directly influenced by the nutrient losses to the environment. According to a survey, about 27% of nitrogenous fertilizers are the major contributor of nitrous oxide. The Red River Valley's losses were estimated to be as low as 0.8% (Zargar et al. 2017).

Soil testing on a regular basis plays an important role to assess the prolonged period effectiveness of nutrient management schemes. Analyzing the soil fertility status on a regular basis plays a vital role in cost-effectiveness, damaging effects in the agroecosystem, and successful agriculture productivity. The different properties of soils such as climate, texture, salt concentration, pH, nutrient availability, and organic matter are considered the key factors to sustainable agriculture (Leogrande & Vitti 2019). Fertilizer recommendations of a certain crop are finalized by conducting a series of research experiments and finding the requirement of the nutrient to fulfill the requirement for metabolic activity and with the findings fitting on response curves and profitability calculated using economic considerations and equations. Adopting appropriate soil fertility gives the following effects in terms of reducing land degradation.

In the early phases of crop development, adequate fertility improves crop vigor and provides great canopy cover, which protects the soil from erosion. Crops absorb nutrients more efficiently as a result of adequate fertility, which benefits both the economy and the environment. A balanced NPK fertilizer improves nitrogen consumption efficiency. Nitrogen losses due to leaching are decreased as a consequence, and groundwater is protected from nitrate pollution.

3.1 Macronutrient Management

3.1.1 Nitrogen

The amount of nitrogen fertilizer needed to ensure optimal crop yield can be significantly influenced by the previous crop. Density, genotypes, straw management, preceding crops, permeability, soil texture, water management, nitrogen fertilizer techniques, soil reactivity, tillage, and nitrogen fertilizer source all influence the nitrogen fertilizer use efficiency. Nitrification and denitrification, as well as diffusion, are the main causes of nitrogen fertilizer loss in rice plants (Fageria et al. 2011). Nitrogen's transformations, effects, and chemical modifications in rice-growing soils in damp climates. Rice grain yield is primarily controlled by tillering, which is directly affected by nitrogen fertilizer rates. The amount of nitrogen applied to rice is highly dependent on the soil makeup. Increased N rates or extra N treatments may be utilized to compensate for leaching losses in sandy course texture soil because the sandy soils have low CEC as compared to fine texture soils. Sandy soils require 50% more N fertilizer than silt and clay loam soils to get the same grain yield. In difficult soil and climatic circumstances, the application of smart nitrogenous fertilizers such as sulfur, polyamine, and neem-coated nitrogen fertilizers may boost rice output (Maghsoodi et al. 2020).

3.1.2 Phosphorous

In plants, phosphorus (P) contributes to straw strength, early maturity, grain quality, and resistance against different diseases. In soil, P is present in two main forms, organic and inorganic, but plant mostly uptakes the nutrient in inorganic form. Organic P (Po) is found in organic matter and biomass in the soil. Some Po must contribute to plant-accessible P, and through the process of mineralization, the organic P converts into inorganic P and is available to plants for uptake for metabolic process. In reality, inorganic P (Pi) regulates P uptake by rice plants (Xu et al. 2010). Five forms of Pi have been identified in soils. The different processes such as diffusion, sorption, and desorption are the major factors which are responsible in maintaining the equilibrium of the level of phosphorus in labile and soil solution. Bronzed leaves are the most common indication of P deficiency, and plants growing in zinc-deficient soil exhibit very similar symptoms. Spraying foliar P at the grain loading stage may also be recommended in industrial agriculture (Mahajan et al. 2008).

3.1.3 Potassium

Plants absorb potassium in the form of the ion K^+. Potassium exists in four basic forms in soil: solution, exchangeable, nonexchangeable, and mineral. All these forms of potassium contribute to the availability of potassium equilibrium. Although K^+ deficiency is considered a major problem in plants, it plays a vital role in the defense system of the plant against different diseases. Due to K pool interactions, K status in the field can easily transition from K-deficient to K-sufficient. In general, foliar potassium nitrate sprays provided better disease protection in rice plants (Olubode et al. 2011).

3.2 Micronutrient Management

Metal micronutrients such as zinc, iron, and manganese have been demonstrated to affect plant growth under climate change scenarios. In a wet moist environment, several mechanisms affect the availability of trace elements, including (1) increased solubility of compounds due to excess water dilution; (2) chemical reaction in the soil profile, which can affect the mineralization and immobilization process of nutrients; and (3) the availability of mineral nutrient that is enhanced due to the increasing mass flow in saturated soil. The uptake concentration of nutrients is directly affected by climatic variations. Under global climatic circumstances, the usage of chelated micronutrients has been found to increase rice output. The three types of iron and manganese present in soil are adsorbed forms of Fe and Mn, organic complexes chelated of Fe and Mn, and varying concentrations of Fe and Mn in soil solution. The organic complex forms aid in plant delivery and absorption, and all of these forms of iron and manganese are responsible for the equilibrium of these nutrients in soil and impact the availability to plants (Tahir et al. 2018; Zain et al. 2015).

4 Conclusion

Sustainable agriculture is directly proportional to soil fertility status and its management. Agriculture productivity is enhanced by nutrient use efficiency, utilization of smart fertilizers, and reduction of their wastage. The problem of climate variability is overcome by enhancing the availability of nutrients and boosting the defense system of plants against different abiotic stresses. Smart management practices such as split use of fertilizers, modern techniques of fertilizer application, water conservation, and adopting the 4R strategies play a vital part in nutrient management under the circumstance of climatic variability.

5 Future Perspectives

Plenty of research work has been done on nutrient management under climatic variability, but still there is a considerable gap to improve nutrient availability under the circumstance of climatic variability. The circulation of nutrients in an ecosystem is very important to enhance the availability of mineral nutrients. The use of integrated approaches is a modern way to enhance the efficiency of nutrient management and ameliorate the toxic effects of climatic variability on the productivity of agriculture. Fertilizer coating and smart nutrient management are virtuous practices to improve the nutrient use efficiency, but huge research work is needed on nutrient management for a sustainable agriculture.

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Modern Breeding Approaches for Climate Change

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Abstract Climate-smart agriculture is the emerging and sustainable option to mitigate the adverse effects of climate change (on crop adaptability) before it significantly influences global crop production. Crop development through modern breeding techniques, effective agronomic practices and exploitation of natural variability in neglected and popular crops are all good ways to meet future food demands. However, the rapidly changing environment requires technological interventions to improve crop climate resilience. Technological advances such as genome-edited transgenic plants, high-throughput phenotyping technologies combined with next-generation sequencing techniques, big data analytics and advances in modern breeding techniques help modern agriculture progress towards robotics or digital conversion to face future environmental adversaries. For example, speed breeding in combination with genomic and phenomic methods can lead to quicker

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_17

identification of genetic factors and, as a result, speed up crop development programmes.

Furthermore, combining next-generation interdisciplinary breeding platforms might open up new opportunities for developing climate-ready crops. Several integrated modern breeding platforms were created in the last few decades and are now employed worldwide. Africa and Asia have adopted these most frequently used crop improvement platforms with advanced techniques like multitrait association studies using genome-wide association studies (GWASs). These have permitted precise exploration of the genetic make-up of agricultural attributes in most crops. This chapter explores various ways to increase crop output by developing climate-resilient superior genotypes. Further, we discussed how combinatorial advanced breeding technologies and biotechnological approaches would be used for managing climate change's consequences to promote crops with climate resilience.

Keywords Biotechnology · Genomic and phenomic methods · Speed breeding · Genome-wide association studies · Next-generation OMICS techniques

1 Introduction

Global wind and precipitation patterns have been altered by the warming climate, which has increased the intensity of extreme weather (Moravec et al. 2021). Farmers worldwide have suffered significant crop losses due to extreme heat and drought. Severe weather occurrences like these and the need to feed an ever-increasing population have generated issues about worldwide food safety. The greenhouse gas (GHG) problem will be met, biodiversity will be protected, economic development and social welfare will be improved, and world hunger will be reduced if we achieve a sustainable environment. A fundamental requirement for attaining sustainable global and regional food production and distribution systems is the faster adoption of new technology. These technologies are required for climate change adaptation and to reduce agriculture's carbon footprint (Zilberman et al. 2018) and are viewed as a precondition for the bio economy's long-term growth (Kardung et al. 2021). Over the previous few centuries, plant breeders have successfully used various breeding tactics and procedures to enhance food output. But agriculture productivity is reduced due to monoculture, resulting in a significant reduction in genetic diversity, and we may not get adequate food from crop plants (Khoury et al. 2014; Hussain et al. 2020a, b, 2022; Ali et al. 2021; Rehman et al. 2021; Mehmood et al. 2021; Waleed et al. 2022).

Climate-smart agriculture is gaining popularity through developing climate-resilient crop varieties (using next-generation breeding techniques) that can tolerate a variety of stressors such as cold, heat, drought, salt, waterlogging, and pressure of pests. Here, we look at the nature and evolution of plant breeding strategies and crop breeding characteristics and how modern technologies can be used to boost crop management in the face of progressively difficult production circumstances. We emphasize a pivotal period in the history of plant breeding. We encourage next-generation breeding as a practically viable route for mitigating the effects of climate change and for developing climate-resilient varieties. Although a complete plan is required, comprising an integrated interdisciplinary strategy (different breeding strategies, seed production, agronomy, pathology, post-harvest techniques and agricultural extension), breeding remains an evident area of progress (Ali et al. 2020; Mubeen et al. 2020; Hussain et al. 2020a, b).

Plant breeding plays a pinnacle role in producing today's high-yielding crop cultivars; however, the speed of crop improvement must be enhanced to meet projected food demands. This can be achieved by combining traditional plant breeding with enhanced agronomic approaches, and this was critical in producing enormous genetic growths in crop harvests between 1960 and 2015 (Grassini et al. 2014). Climate change has aided the evolution of better cultivars. Resilient crops are essential for boosting yield synchronous to the rising human population. As a result, improvement in conventional farming growth should be aided by marker-assisted breeding approaches by expanding crop genetic improvements (Varshney et al. 2018; Ali et al. 2019; Rahman et al. 2018, 2019; Amin et al. 2018a, b; Nasim et al. 2018a, b; Hammad et al. 2018). Marker-assisted plant breeding is essential in the future for attaining rapid progress in crop production in a short period.

Modern breeding technologies are also being given due consideration in developing countries. For example, in Africa, plant breeding is an ancient science studied for centuries and is now being facilitated by the quick combination of advanced skills, such as biotechnology, to witness more agricultural development. The African Agricultural Technology Foundation (AATF) has been at the forefront of the agricultural revolution, exploring innovations that might help Africa achieve food security. The critical, creative initiatives and other regional developments that are accelerating Africa's agrarian transformation are as follows:

1. Breeding programmes and biotechnological interventions contribute to Africa's food and nutrition.
2. The AATF's contribution to smallholder farmer (SHF) technology access, adaption, delivery, and stewardship.
3. The pattern changes to agribusiness to achieve SDG goals, particularly in decreasing poverty, guaranteeing food security, combating hunger and promoting environmentally sustainable natural resource management.

1.1 Climate Resilience Agriculture: Mitigation and Adaptation

Mitigation (cutting emissions) and adaptation (increasing resistance to climate effects) are two climate change priorities that run across all strategic objectives and are integrated throughout the framework. Other management alternatives, like the manufacturing of weather-resistant agricultural equipment, the changing of planting and cropping dates and climate forecasts through remote sensing and modelling, can also be utilized to address climatic challenges.

Mitigation is described as a type of intervention that minimizes the severity of climate change by lowering the amount of greenhouse gases emitted into the atmosphere, such as nitrous oxide, CO2 and methane. Breeding strategies play an essential role in reducing greenhouse gas emissions such as methane and nitrous oxide from numerous sources (soil and feeding animals) and have the capacity to collect carbon directly from plants and soils (Awais et al. 2017, 2018; Amin et al. 2018a, b, c; Fahad et al. 2018; Senapati et al. 2019). Adaptation is a significant element in preventing climate-related hazards in agriculture and helps in limiting the adverse effects of climate change. Climate change adaptation also requires formulating early maturing, heat- and drought-resistant plants to maintain production. Adapting climate-smart new cultivars would enhance productivity per unit area under these environmental extremes (Deressa et al. 2009).

1.2 Climate Change in Developing Countries: Need for Modern Breeding Technologies

Crops, localities and adaptive capabilities to climatic hazards influence the natural effect of temperature change on cultivation (Tariq et al. 2018; Vermeulen et al. 2012), so adaptability also impacts agricultural production (Panda et al. 2013; Aryal et al. 2018). Persons in the Hindu Kush Himalayan area, which includes areas of Pakistan, India and Nepal, for example, are most susceptible to climate change due to their reliance on agriculture for a living, their physical separation, low productivity, limited access to global markets and poor road networks (Rasul et al. 2019).

The Intergovernmental Panel on Climate Change (IPCC) identifies climate change as a change in the average value and/or variance of the atmosphere's characteristics that lasted at least decades or more (Field and Barros 2014). Agriculture is vulnerable to climate change: rising temperatures and decreasing rainfall in semi-arid areas are expected to reduce yields for various staple crops over the next two decades. Similarly, the intensity and distribution of pest and disease outbreaks may also become more unpredictable, posing severe threats to agricultural productivity (Oszako and Nowakowska 2015). While the actual effects of climate change on agroecosystems are expected to be severe, the impacts are different (in type and degree) across geographical areas (Mba et al. 2012; Nasim et al. 2012a, b, c; Nasim and Bano 2012; Mubeen et al. 2013; Sultana et al. 2013; Amin et al. 2015). Developing countries are likely to be affected by their mostly low-input cropping system, which depends on somewhat predictable weather conditions (especially rainfall) and their ever-increasing population, which defines the number of suitable acres for farming (Yadav et al. 2011). So, there is a dire need for developing countries to adopt some new plant breeding approaches to cope with climate change impacts.

2 Crop Improvement from Classical Breeding to the Application of Biotechnology: A Climate Resilience Perspective

2.1 Conventional Breeding

Plant breeding based on phenotypic selection has long been used in Africa to improve and develop crops. In Africa, the earliest breeding efforts were mainly focused on yield and component attributes. However, as the focus turned to industrial features, this quickly switched to the quality features for farmer preferences to increase acceptance and improve markets. Beyond yields and pest resistance, the breeding programmes have expanded over time to find additional features, having screening for unusual qualities in the collections. Improved seed biology, abiotic and biotic stress tolerance/resistance, agriculture resource use efficiency and new market-driven post-harvest attributes are unique features being pursued to help genuinely sustainable agriculture in Africa. Some of the traditional breeding strategies employed in Africa include germplasm gathering and population improvement, recurrent selection, genetic stock generation and hybrid development through heterosis.

2.1.1 Germplasm Assemblage and Population Improvement

Genetic diversity provides variations of alleles suitable to breeding elite lines for adaptability to varying environments, plant suitability and other breeding concern qualities. A limited genetic basis is a critical limiting factor in population development and a chief bottleneck in many African breeding operations (Hammad et al. 2010a, b; Nasim et al. 2011; Munis et al. 2012; AGRA 2017). Thus, the establishment of many breeding programmes in many nations has relied heavily on the generation of genetic variation through local germplasm collections and imports into Africa from centres of origin (Varaprasad and Sivaraj 2010). Massive germplasm banks have been established throughout Africa. They are projected to continue to increase to fulfil the changing requirements of humans and the ever-increasing economic potential for cash and commercial crops.

2.1.2 Limitations of Classical Breeding

Despite the considerable success of traditional breeding efforts, the methods are time-consuming and laborious – developing and releasing a variety takes typically 8–10 years. If biotic limits are difficult to overcome, it takes a longer time. Pyramiding and understanding the establishment of different beneficial alleles for native traits are the basis for novel crop development opportunities in the twenty-first century (Varshney et al. 2012). Tragically, they are not easily achievable by traditional breeding methods. Conventional breeding has many constraints on genetic resource conservation, the formation of heterotic pools for hybridization, the purification of genetic stocks to eradicate viruses, pre-breeding to reduce genetic burden, screening for allelic variations and fast multiplication of vegetatively propagated crops. Due to these restrictions and to explore speedy crop improvement processes, there is a need to find new horizons of genetic modification, which biotechnology may offer. Immense biotechnology financing has delivered many of the novel breeding techniques that have quickly added a proportion to the science of variety production and provided a significant role in understanding genetics. Biotechnology has revolutionized breeding throughout the globe. In contrast, some progress has been made in integrating research products and channel development in Africa, and it has been employed more effectively in other regions.

2.2 The Plant Genome Editing Era

Although breeding in classical ways is faster today than it was 50 years before, it is still insufficient to meet the world's need for crop production (Wajid et al. 2010; Usman et al. 2010; Breseghello and Coelho 2013; Voss-Fels et al. 2019). Additionally, transgenic technologies and mutation breeding could be used to insert novel genes for crop breeding. However, genetically modified organisms remain prohibited in many countries due to concerns about the healthcare system and regulations. Breeding a crop cultivar by conventional transgenic and mutational breeding typically takes 10–12 years (Razzaq et al. 2019b). There are three techniques for increasing agricultural output and stability significantly:

(a) Mutation breeding
(b) Genetic engineering
(c) Directed modification

The strategy of exposing seeds to chemicals or rays to improve variants with desirable qualities (having the ability to cross with other cultivars) is known as mutation breeding. Synthetic biology approaches facilitate the formation of extended DNA fragments with specific sequences, and also crop genetic engineering with known genome sequences permits the generation of agronomically significant variants (Wajid et al. 2007, 2010; Ahmad et al. 2009; Usman et al. 2009). Resistance to herbicides and insects is now the most extensively used genetically modified feature in crops, and it has been integrated into *Zea mays* (maize), *Gossypium hirsutum* (cotton), *Glycine max* (soybean) and *Brassica napus* (canola). For majority of the time, they are monogenic features. Targeting specific DNA sections or specific genetic codes with significant agronomic characteristics for DNA editing is directed modification.

2.2.1 Citizen Resistance to Genetically Modified Organisms Risks Overshadowing the Contribution of Other Biotechnologies

Since the 1990s, there has been a passionate debate about genetically modified organisms (GMOs). Different factors like food quality, ecology, diversity, human health and international food management having possible effects due to GMOs are discussed in this debate. It is stated that genetic modification can aid in the enhancement of production and productivity in a few circumstances. One undesirable side effect of this long-running discussion is that other biotechnologies' advances have been overlooked. For example, biotechnologies have been used to produce New Rice for Africa (NERICA) cultivars, which allow African and Asian species of rice to be intercrossed. NERICA rice cultivars, which unite Asian rice's high productivity with African rice's capacity to flourish in severe climates, are now extensively available in Africa's sub-Saharan. Biotech crops have been the most protrusive crop technology (James 2014).

Another instance is the present research on perennial rice in China, which can regrow rice season after season without being reseeded. China provides ten times more funding for agriculture than India and Brazil; these two nations are expanding much more than the total of African sub-Saharan. Enhanced north-south linkages are vital to fostering capability and rapid technology flow since most innovative biotechnologies are created outside low-income nations.

3 Evolution of Plant Breeding Strategies for Future-Generation Climate-Smart Crops

Plant breeding originated as an effective technique for domesticating plants around 10,000 years ago when wild relatives were used to select desirable features through a continual procedure for selecting over multiple generations for crop development (Purugganan and Fuller 2009). Many essential crops have been established through breeding and are widely farmed worldwide. Figure 1 highlights some of the most significant accomplishments in plant breeding history. Many agronomic features, for example, were haphazardly integrated into diverse crop species in the pre-genetic period. Plant breeding has gained fresh insight due to Mendel's rules of inheritance and the ongoing finding of genetic factors. Scientists are permitted to recognize genomic areas, which will be later designated as genes that determine

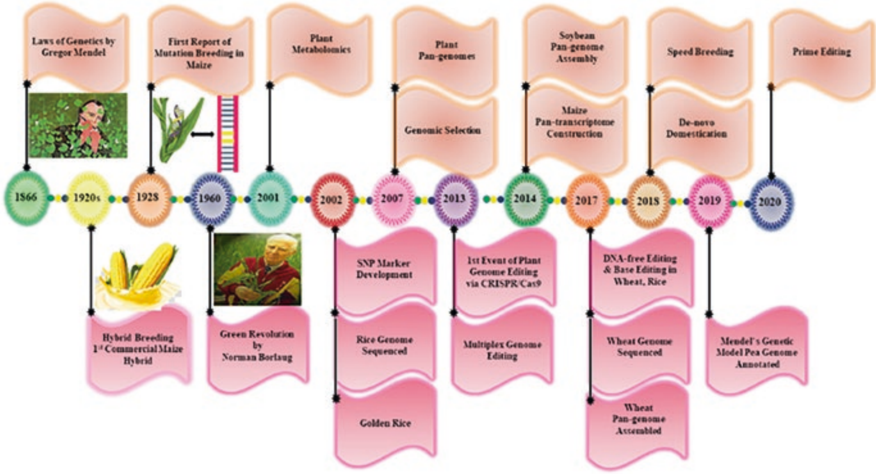

Fig. 1 Representations of the major achievements of traditional and modern plant breeding

agronomic features in plants, and it has become possible after 100 years of continuous research (McCouch et al. 2013). In the 1960s, the Green Revolution significantly improved the production potential of several main crops, such as wheat and rice, to satisfy rising food demands worldwide, including in many developing countries like India and Pakistan (Saeed et al. 2013; Nasim et al. 2007, 2010).

On the other hand, plant breeding has been under great pressure since then to maintain a stable agricultural production with limited water resources, land usage and fertilizer sources. To deal with these issues, plant scientists must understand distinct genetic elements to develop cultivars of exceptional quality that are more resistant to stress and yield more grain. In general, premium cultivars have been developed through crossbreeding, and in conventional breeding, a constant technique for screening has been used (Purugganan and Fuller 2009). Plants with innovative agronomic traits have the greatest genomes intercrossed, and ultimately, wild relatives or arable landraces with superb qualities are selected (Lavarenne et al. 2018). Plant breeding and food production are still being revolutionized because of advances in biotechnology. A vast range of novel plant breeding technologies (NPBTs) has been developed due to these advances in biological understanding. Site-directed mutation (SDM)-based NPBTs allow for targeted modifications in double-stranded plasmid DNA. Techniques like CRISPR-Cas 9, TAL effector nucleases (TALEN), and oligonucleotide-directed mutagenesis (ODM) develop plants with desired characteristics. They have the benefit of being more accurate and faster to be deployed than conventional plant breeding methods (Purnhagen and Wesseler 2021). However, a difference is frequently established between traditional methods and NPBTs in both literature review and regulatory approaches taken by the state. Most regulators consider standard procedures "safe" plant breeding methods, whereas NPBTs may not be safe in many countries, despite the scientific consensus that the older techniques are not much safer (Wesseler and Zilberman 2021).

This section will discuss technological intervention in modern breeding technologies for developing future-generation climate-smart crops.

3.1 Speed Breeding

The most innovative technique of speed breeding (Watson et al. 2018a, b) formed guidelines for various plant species and has attracted the attention of the entire globe. Speed breeding is a valuable approach for reducing crop generation time and accelerating crop improvement activities (Watson et al. 2018a, b). Plants are treated to a prolonged photoperiod of around 22 h by employing various light sources in speed breeding. It gives a more extended day with ideal light intensity and a regulated temperature to boost photosynthetic activity, resulting in faster blooming and seed development, reducing the period for next generation (Ghosh et al. 2018).

Speed breeding is altering farming, and it may be used to speed up processes like crossing, quick identification of genes, population mapping, trait pyramiding, backcrossing and producing transgenic lines. In traditional breeding, only 1–2 generations of the crop may be achieved every season; however, in speed breeding, more than four generations of any crop can be obtained per season. Moreover, it can achieve a reliable, competent and cost-effective platform for holistically carrying out crop development projects from genetics through phenomic analysis. It could involve discovering candidate genes using genomic-assisted breeding (GAB) techniques like pan-genome assembly, genomic selection (GS) and genotyping by sequencing (GBS) for desirable attributes, multiple gene editing or metabolic pathway alteration, followed by high-throughput phenotyping (Pandey et al. 2022). Integrating speed breeding with next-generation metabolomics tools can facilitate a quick risk assessment of gene-edited crops for many generations (Razzaq et al. 2019a). As a result, combining speed breeding technology with next-generation OMICS techniques (e.g. genomics, transcriptomic, metabolomics, proteomics and interactomics) to expedite agricultural breeding projects will provide an exciting path forward for crop improvement.

3.2 Next-Generation Breeding Strategies

Next-generation breeding, we believe, is a relatively viable route ahead for mitigating the climate change implications and promoting climate-resilient crops for improved production. Although a complete plan requires a transdisciplinary and interconnected plan of action (pathology, agronomy, seed production, post-harvest techniques, extension services, satellite-based sensing, artificial intelligence and various breeding strategies), breeding remains an identifiable site of progress. Figure 2 shows how a transdisciplinary plan of action is achievable when we go for next-generation breeding.

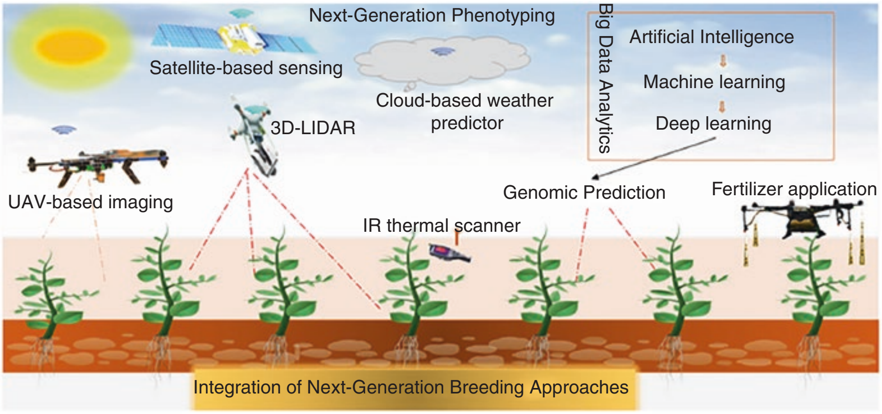

Fig. 2 Connectivity of breeding networks for the better future

3.3 Fast-Forward Genomic-Assisted Breeding (GAB)

Plant breeding has been transformed by modern plant breeding techniques, which have evolved as a potent alternate to traditional breeding. Plant genomics is essential for accelerating breeding programmes and improving crop performance, including identifying traits and finding heritable variants that manage crop performance and boost stress resilience within the crop genome (Bevan et al. 2017). Plant genomics is an essential component of omics research that focuses on the entire plant genome to determine its structure and function. It is important to take information from within the genome by designing a precise preparation of DNA sequencing that may be used to investigate genomic progression and evaluate molecular phylogenetic connections (Varshney 2016). Multitrait studies using genome-wide association studies (GWASs) have permitted accurate exploration of the genetic make-up of agricultural attributes due to fast-forward genotyping and phenotyping platforms.

3.4 Genome-Wide Association Studies (GWASs) for Stress Tolerance

Genome-wide association studies (GWASs) are a robust method for analysing the whole set of genetic variations in various agricultural cultivars and identifying allelic variants connected to any given attribute. GWASs consider the relationship between single-nucleotide polymorphisms (SNPs) and phenotypes and are built on GWAS design, genotyping techniques, statistical models for analysis and finding interpretation. Many crops have undergone GWAS to utilize the genetic mechanism that causes genetic resistance due to climate change. GWAS has a wide range of plant applications for biotic and abiotic stressors. Drought tolerance, salt tolerance and heat tolerance have been studied using GWAS (Thoen et al. 2017).

3.5 SNP-Based Marker

SNP markers have become extremely popular in plant molecular genetics due to their genome-wide abundance and amenability for high- to ultra-high-throughput detection platforms. The numerous SNP genotyping platforms may be divided into (a) genotyping-by-sequencing (GBS) methods based on next-generation sequencing technologies, (b) those platforms that use fixed SNP assays and (c) SNP assays that run one marker at a time (uniplex), usually PCR based (Orjuela et al. 2014). Latest SNP-based markers like KASP (kompetitive allele-specific PCR [KASP] markers for potato) have recently been used in some studies. KASP markers provide high-throughput gene tagging in many crops, including wheat and soybean breeding. It is a cost-effective method. The cost can be further lowered if we use alternate master mix solutions. Newly developed KASP assays at the Muhammad Nawaz Sharif University of Agriculture, Multan (Pakistan), is a step forward in this technology and can provide a central genotyping facility under the National Crop Genomics and Speed Breeding Center for Sustainable Agriculture (Rasheed et al. 2016; Irshad et al. 2021).

4 Conclusion

Plant growth and yield are both affected by climate change. The most common sort of stress that plants face is abiotic stress. The most critical present prerequisite is to examine the genetic foundation to comprehend plant responses to diverse abiotic circumstances. Breeding techniques will involve the development of climate-resilient crops that are more compliant with water stress and heat. In finding the distinct genes for crop improvement in global warming adaptation, genome-wide association studies (GWASs) and genomic selection (GS) with elevated phenotyping and genotyping techniques are important. Using genetically engineered approaches, foreign genes with improved tolerance to diverse biotic and abiotic stress responses have been constructed. Consumer acceptability is seen as a critical barrier to adopting food made with NPBTs in many countries. However, empirical analysis suggests that huge community sectors are prepared to purchase and consume such foodstuffs, even if they are just marginally cheaper. Furthermore, when it is evident that a new food product generated from NPBTs is of more outstanding quality, people are prepared to pay a premium.

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Heat Stress Tolerance in Crop Plants: Physiological and Biochemical Approaches

Abida Aziz, Iqra Wazir, and Muhammad Farooq Azhar

Abstract The rising temperature of the environment has resulted in heat stress for several agricultural crops and worsened food availability and nutritional security across the globe, in general, and developing countries, in particular. Heat stress is associated with drought and affects not only the plant growth but also its metabolism and yield potential. It is established evidence that developing countries of the southern hemisphere are at more risk of catastrophic loss of plant yield which can lead to famine. High temperatures can cause heat stress in the food crop plants, and their physiology, biochemical behavior, and gene regulation pathways can all be affected. Each crop species has its own withstanding temperature which it can tolerate; otherwise, the crop will show adverse effects. The reproductive or propagating stage of the plant is highly susceptible to heat stress. A temperature rise at this stage can result in bud dormancy and flower abortion. One consequence of heat stress is loss of water content in the crop plant which can inhibit the seed filling process or retard it. Other impacts of heat stress on crop plants include alteration in photosynthesis and respiration processes, affecting the membrane stability of the leaf and causing water imbalance. In response to high temperatures, crop plants respond with a tolerance mechanism composed of various biochemical factors which include heat shock proteins, osmoprotectants, ion transporters, and production of antioxidants. Plants also respond with some physiological behavior including leaf rolling, leaf senescence, inhibited stomatal conductance, and transpiration cooling. In most of the developing countries, wheat and potato are basic staple foods and significantly affected by heat stress. Moreover, the need of the hour is to produce such cultivars of crop plants and breed the best cultivars which are tested and produce good yield even in heat stress so that the world climatic change do not show adverse food shortage in the near future.

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_18

Keywords Heat stress · Crop plant tolerance · Physiology · Biochemical pathways · Cultivars

1 Global Temperature Rise and Its Relation to Heat Stress in Crop Plants

1.1 Global Temperature Rise/Climatic Change

The world has been going towards some drastic climatic changes in the past few decades which are a result of human activity and industrial revolution. The temperature of the world is rising due to greenhouse gases, mainly CO_2. The accumulation of this greenhouse gas in the atmosphere has resulted in heating of the planet as it traps infrared (IR) radiations from the Earth followed by sunlight. This constantly increases the temperature of the Earth resulting in global warming (Zandalinas et al. 2021). Global temperature is predicted to uprise by the end of the twenty-first century by an average of 2–4 °C due to anthropogenic and natural factors (Asthir 2015; Amin et al. 2017a, b; Shakeel et al. 2017; Jabran et al. 2017a, b; Hammad et al. 2017; Gillani et al. 2017; Ahmad et al. 2017; Nasim et al. 2017).

The rise in the global temperature means more heat waves and drought and also other abiotic conditions like salinity, flooding, and freezing stresses (Zandalinas et al. 2021). The human population is growing and so is the demand of food and food crops. It is immensely important to understand that plants are affected with high temperatures, causing a problem in fulfilling the world's food demand (Abbas et al. 2017; Fahad et al. 2017; Saud 2017; Zia et al. 2017; Hassan et al. 2021).

1.2 Abiotic Stress in Plants

Plants are sessile; thus, they face all the environmental changes in their surroundings. A nonliving factor that affects plant growth and development is called abiotic stress. High temperature is considered as the most prominent abiotic stress in plants (Hemmati et al. 2015). Other abiotic factors causing stress in plants are cold, drought, salinity and heavy metals. These environmental changes affect plant growth, development and yield (Imran et al. 2021). Abiotic stress in plants is considered one of the prime causes of lowering crop productivity which leads to substantial yield loss, thus resulting in food shortage (Ahmad et al. 2017; Sehgal et al. 2018).

1.3 Food Crops

Food crops can be indigenous, endemic, and traditional having multiple uses in society. They not only diversify our food but also ensure nutrition security by increasing food resources (Akinola et al. 2020). The basic purpose of food crops is to fulfil the food demand and meet the requirement of food around the globe. The world population may reach 10 billion by 2050; thus, there will be increase in the food demand. To fulfil the rising food demand of the increasing population, the biggest challenge will be to produce sufficient food, but shortage of agricultural land in the near future and adverse environmental changes can be a great threat in food crop shortage (Awais et al. 2017a, b; Mahmood et al. 2017; Nasim et al. 2017; Govindaraj et al. 2018).

1.4 Importance of Food Crop Productivity to the World

Agriculture is dependent on weather and climatic conditions. Any change in these conditions can result in crop loss and food concerns. The food crop productivity is directly related to environmental conditions, i.e., good environmental condition for a food crop, and then good yield and adverse environmental conditions mean yield loss. But this loss is not limited only to food production. Its adverse effects are seen in high food prices and it also threatens food security. Food crop productivity is of immense importance to the world in terms of food prices, food security, and food demand (Bandara and Cai 2014; Nasim et al. 2016a, b, c).

2 Heat Stress and Crop Plant Physiology and Biochemical Behavior

2.1 Crop Plants' Maximum and Minimum Tolerable Temperatures for Growth

Crop plants have some threshold temperatures (TT), i.e., a mean temperature where reduction in plant growth starts. Basically, it is a range of maximum and minimum temperature that a plant can tolerate; some changes at threshold temperature are reversible but some are irreversible. The photosynthetic capacity is irreversible, whereas flowering, growth, etc. are reversible. Every crop plant, for example, wheat, maize, and rice, has different threshold temperatures for different developmental stages. If the threshold temperatures increase, the crop experiences stress. Table 1 provides different threshold temperatures of different food crops. Food crops in the cold region or growing in cold seasons have lower TT than crops grown in tropical regions (Govindaraj et al. 2018).

Table 1 Threshold temperatures of various plants (Kaushal et al. 2016)

Plant name	Scientific name	Threshold temperature (°C) (TT)	Plant developmental stage
Cereals			
Wheat	*Triticum aestivum*	21–31	Vegetative
		15	Reproductive
Maize	*Zea mays*	32–38	Photosynthesis
			Pollen viability
Rice	*Oryza sativa*	32.9	Biomass
		25	Grain formation, yield
Sorghum	*Sorghum bicolor*	25.9–35	Vegetative
		25–28	Reproductive
Legumes			
Common beans	*Phaseolus vulgaris*	23	Yield
Peanut/ groundnut	*Arachis hypogaea*	30–34	Vegetative
		23	Anthesis
			Pod, seed yield
Soybean	*Glycine max*	25	Reproductive development
		22	Post-anthesis
		30.1	Pollen germination
		36.1	Pollen tube growth
Pea	*Pisum sativum*	15–20	Vegetative growth
		28–30	Growth
Mung bean	*Phaseolus aureus*	10–30	Flowering
			Pod development
Chickpea	*Cicer arietinum*	15–30	Growth
		25	Reproductive growth
		22–25	Fruit growth
		17–18	Fruit size
Other crops			
Tomato	*Lycopersicon esculentum*	37	Vegetative development
		28–30	Reproductive development
Cotton	*Gossypium hirsutum*	40/30	Vegetative biomass
		32/22	Pollen viability
		43.9/33	Photosynthesis
		37/25	Seed size
Brassica spp.		30	Flowering

2.2 Heat Stress Effect on Crop Plants

Heat stress can have some adverse effects in crop plants which can be morpho-anatomical, physiological, and biochemical; all these changes adversely affect the growth and development of plant and lower yield. Heat stress affects plants in two ways:

1. *Direct injury*: it is related to denatured accumulation of proteins and increased fluidity of membranes.
2. *Indirect injury*: it involves inhibition of protein formation, mitochondrial and chloroplast enzyme deactivation, protein degradation, and membrane integrity loss, resulting cell death.

Heat stress reduces the photosynthetic activity of the plant as the more reactive oxygen species (ROS) are produced which can cause cell injury or death; reproductive processes are also affected by heat stress, which include pollen germination, growth of pollen tube, viability of ovule, position of stigma and style, pollen retention on stigma, and both fertilization and postfertilization processes. Heat stress also affects endosperm growth and causes an effect on proembryo and fertilized embryo (Kaushal et al. 2016) (Fig. 1).

2.2.1 Physiological Changes

Photosynthesis is considered as one of the most important physiological processes of plants and is a heat-sensitive process. Heat stress in plants cause some drastic effects on their photosynthetic activity. C_3 and C_4 plants are highly affected by high temperatures. At high temperatures, the internal machinery of the chloroplast gets disturbed which involves carbon metabolism of stroma and photochemical reactions of the thylakoid lamellae. In heat stress the thylakoid membrane is highly affected, the grana losses stacking and swells at high temperature, and the entire photosystem is disturbed and its activity reduced. Due to heat shock, the amount of photosynthetic pigment is also reduced (Hasanuzzaman et al. 2013; Alghbari et al. 2016; Fahad et al. 2016a, b; Mubeen et al. 2016; Rasool et al. 2016).

There are other physiological changes in plants too due to heat stress, which include increased respiration, reduced water potential, and decreased thermostability of the cell membrane (Bita and Gerats 2013).

Physiological injuries, also termed as morphological changes in plants at high temperatures, includes scorching and sunburn on leaves, discoloration of fruits, fruit damage, leaf senescence, and abscission plus shoot growth inhibition (Khawar et al. 2016; Nosheen et al. 2016; Fahad et al. 2016c, d; Kaushal et al. 2018).

2.2.2 Biochemical Changes

In heat stress, plants undergo some biochemical changes which include production of ROS species, also known as oxidative stress. This oxidative stress greatly affects the PS I and PS II of the chloroplast. Other major sites where ROS amount increases are plasma membrane, mitochondria, endoplasmic reticulum, peroxisomes, and apoplast. Heat stress also causes some problems in the homeostatic

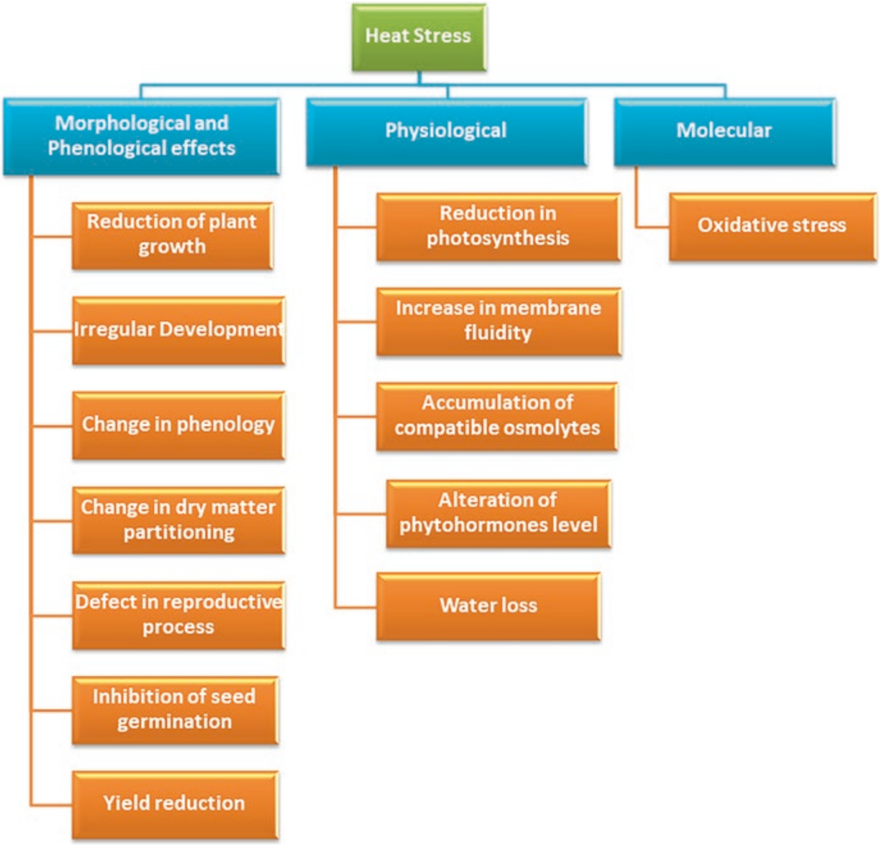

Fig. 1 Effects of heat stress on plants (Hemmati et al. 2015)

control of the plants, especially hormones. Accumulation of thermoprotectants and changes in the metabolism of carbohydrates and nitrogen are also some metabolic changes observed in plants experiencing heat stress (Amin et al. 2015; Kaushal et al. 2016).

2.3 Heat Stress and Crop Productivity

Crop productivity is associated with plant yield. Heat stress causes the plant growth to cease and sometimes damage the plant completely in case of severe droughts. Photosynthetic activity is ceased in heat stress which results in less biomass of the plant and decreased yields. High temperatures affect the grain yield along with the crop quality and characteristics. A slight increase in temperature, even of 1.5 °C, can have adverse effects on crop productivity.

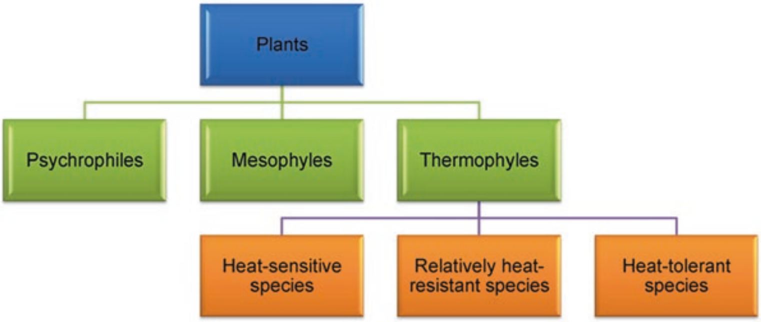

Fig. 2 Classification of plants on the basis of heat tolerance (Hasanuzzaman et al. 2013)

Wheat is a winter season crop; during heat stress, its productivity is decreased as the elevated temperature affects its yield. Same is the case with rice, i.e., if the temperature rises above 25 °C during grain filling, its productivity is decreased. Potatoes grow in a narrow temperature range, i.e., 18–20 °C, the threshold temperature is 20 °C, and if the temperature is elevated in the tropical regions, then its productivity is decreased. A rise in temperature or heat stress can result low crop productivity (Kaushal et al. 2016).

3 Adaptations of Plant Crops to Heat Stress

3.1 Classification of Plants on the Basis of Heat Tolerance

Plants can be classified on the basis of varying heat tolerance as follows:

1. *Psychrophiles*: grow in low temperature 0–10 °C
2. *Mesophytes*: favor moderate temperature 10–30 °C
3. *Thermophytes*: can grow well between 30 °C and 65 °C or even higher (Hasanuzzaman et al. 2013) (Fig. 2)

3.2 Mechanisms of Heat Tolerance in Plant Crops

Heat stress tolerance is basically a plant trait in which a food crop can grow and produce economically under heat stress (Hassan et al. 2021). The heat tolerance mechanism in crop plants is linked with the duration, intensity, and rate of temperature change. Plants prepare a response upon the above factors. The mechanisms which are involved in plant defense are physiological and biochemical as well. A phenomenon known as *heat acclimation* is important for crop plants as it provides a pretreatment with moderately elevated, considerably nonlethal temperatures which may temporarily increase plants' tolerance to subsequent, potentially fatal thermal stress. This heat acclimation and tolerance is important for crop plants. Some diverse heat stress responses by plants include change in leaf orientation, leaf rolling, transpiration cooling, antioxidant response, osmoprotectants, phytohormones, alterations of membrane lipids, small leaves, and early maturation (Kaushal et al. 2016).

3.3 *Plant Physiological Response*

3.3.1 Plant Growth and Reproduction

Plant growth is significantly affected by heat stress. The process of photosynthesis is heat sensitive, and if heat tolerance in crop plants is considered, then it means a minimum photosynthetic machinery damage and more biosynthesis of protective compounds. In order to produce heat-stress-tolerant crop plants, it is important to produce a variety that is more likely to tolerate the fluctuating temperatures. Heat-tolerant cultivars are considered one of the best options in this regard and they can be grown by conventional breeding. Growing cultivars that are more likely to resist high temperatures will resolve the problem of plant growth and reproduction, which is carried out after several trials and tests, and the best cultivar is selected to grow as a food crop.

3.3.2 Leaf Rolling

Leaf rolling is a morphological response in heat stress. It is important for plants under stressed conditions as it reduces the surface area for solar radiation absorption. Small leaves tend to survive more in heat stress conditions than plants with larger leaves. It is through a short-term adaptation, but it is effective in drought or heat stress conditions.

3.3.3 Leaf Senescence

Leaf senescence is considered one of the important agronomic traits. Leaf senescence not only limits the yield and biomass but it also modifies the nutritional value (Woo et al. 2018). Heat stress causes premature leaf senescence in various plants, for example, research revealed that few rice mutants showed premature leaf senescence and were involved in heat tolerance (He et al. 2021). As a result of leaf senescence induced by heat stress, plant experiences loss of chlorophyll from leaves (Jespersen et al. 2016).

3.3.4 Pollen

Pollens are considerably more heat sensitive than other vegetative parts of the plant and the female gametophyte. It is most affected at early developmental stages which involves anther wall development, microgametogenesis, and microsporogenesis. Some recent research suggests that the pollen response to heat stress is epigenetic and transcriptomic but still there is a need of more detailed research to make improvement in thermo-tolerance of food crops (Raja et al. 2019).

3.3.5 Seed Filling

Seed filling is an important developmental stage for all food crops, including the dynamic and transport processes necessary for the import of various components and various biochemical processes (carbohydrates, proteins, and lipid synthesis). The quantitative and qualitative traits of the final yield of the food crops depend on the processes of seed filling which involves the reserves' assemblage in developing and maturing seeds. These processes are highly sensitive to changes in the environment. The seed size and weight are affected by the duration of seed filling. Heat stress affects the seed filling duration and its constituents (Sehgal et al. 2018). Wrinkled seed and seed filling in heat stress is accelerated; thus, the duration is reduced which limits the yield potential (Kaushal et al. 2016).

3.3.6 Stomatal Conductance

Heat stress ensues leaf rolling and small leaf size and also results in low leaf water potential. Rising temperatures result in increase stomatal conductance resulting in evaporative cooling (Urban et al. 2017).

3.3.7 Membrane Fluidity

During heat stress conditions, the membrane fluidity increases and it can happen due to denatured proteins or compounding of unsaturated fatty acids. The membrane permeability is increased as the tertiary and the quaternary structure of the protein becomes alert at high temperatures. Gene expression is affected by high temperatures, thus changing membrane fluidity (Hemmati et al. 2015). The thermostability of the membrane has been successfully employed in order to access thermotolerance in food crops (Kaushal et al. 2016).

3.4 *Plant Biochemical Behavior*

3.4.1 Ion Transporters

The entire plant homeostasis process is disrupted in heat stress. As plasma membrane is affected with elevated temperatures, the ion transporters in plants also experience leakage. If plant heat acclimation is carried out, then it can help resolve the problem to some extent (Ilík et al. 2018).

3.4.2 Exogenous Protectants (Osmoprotectants, Phytohormones, Antioxidants)

Application of exogenous protectants like osmoprotectants, signaling molecules, phytohormones, and trace elements has shown some good results for plants under heat stress. These protectants promote growth and antioxidant capacity (Hasanuzzaman et al. 2013). Exogenous antioxidants, proline and glycine betaine, improve K^+ and Ca^{2+} content and add more endogenous proline or glycine betaine and soluble sugars. This makes plants tolerate heat stress to a greater extent (Asthir 2015).

3.4.3 Transcriptional Control

Gene upregulation has helped plants in heat stress conditions. In this scenario the signaling pathways regulate plants' response to heat stress which can also lead to plant adaptation to its surroundings. These signaling pathways activate the stress-responsive gene which then activates the antioxidant enzymes, maintain protein structure, and maintain cellular homeostasis (Hasanuzzaman et al. 2013).

3.4.4 Antioxidants

In response to signaling pathways and stress response, gene activation antioxidants are produced to fight ROS. These antioxidants, for example, proline, act as a molecular chaperon; it not only maintains protein integrity but also improves the enzyme activity. It is considered as a ROS scavenger (Hayat et al. 2012).

3.4.5 Heat Shock Proteins (HSPs)

Heat shock proteins are formed as a result of gene upregulation and in order to activate heat-stress-responsive genes or heat shock genes. HSPs are very diverse in nature and constantly expanding. The expression of HSPs is limited to specific developments of plant stages like embryogenesis, seed germination, fruit maturation, and microsporogenesis.

The function of these proteins is to maintain the structural and functional conformation of the membranes and enzymes and ensure that they are working correctly even at high temperatures. (Hassanuzaman et al. 2013).

3.4.6 Metabolites

At high temperatures plant accumulates different metabolites which include antioxidants, phytohormones, osmoprotectants, and heat shock proteins. It results in the activation of various metabolic pathways and processes.

4 Food Crop Engineering to Produce Heat-Stress-Tolerant Crop Plants

4.1 Breeding

To achieve economically desirable crop plants, breeding is considered one of the best options as desired traits can be produced. Targeted breeding has reduced genetic diversity in hybrids or commercial varieties with homogenous appearance. The use of germplasm in breeding is considered to produce heat-tolerant plants (Govindaraj et al. 2018).

4.2 Cultivars

Genetic engineering can be used to produce cultivars which can tolerate environmental stresses and provide a good economical yield (Shakeel et al. 2014; Hammad et al. 2014; Zaffar et al. 2014; Asthir 2015). Cultivar is a plant variety which is produced by selective breeding to achieve desirable traits of the food crop. Cultivars are a result of selective breeding in which only the genes for desired traits are picked and different methods can be used to grow a cultivar. All the research for a desired trait is carried out first, and then through selective breeding, a heat-tolerant plant can be grown (Wikipedia).

5 Conclusion

In an era where the world is going towards abrupt environmental changes, food crises, shortage, and rise in food prices, it has become much important to understand that it is the need of the hour to produce cultivars which can withstand high temperatures and a multirange of studies and research are required to pick for the best and desired traits. Due to heat stress, pollen, seed filling, flowering, and almost every crucial process of the plant are affected; thus, a great deal of work is being conducted to produce heat-tolerant plants. The use of germplasm to produce desired traits is considered as the best practice to produce heat-tolerant plants. The flowering time of the plant is crucial for crop productivity so in this scenario the breeders need to devise some tools for heat tolerance screening at the time of flowering. Besides this, there are also some technology applications in food crops which include nanoparticles. Several different studies are being carried out to check the application of nanotechnology to food crops to minimize heat stress. The use of nanotechnology is a new approach and very few labs are exploring it. Agricultural practices are significantly improving with technology and biotechnology and this can help to produce heat-tolerant plants.

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Crop Protection Under Climate Change: The Effect on Tri-trophic Relations Concerning Pest Control

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Abstract Climate as the primary determinant of agricultural productivity is important under climate change. At various levels, several types of plant disease and arthropod population models are developed to include more precise and accurate climatic projections. Changing patterns of rainfall, humidity, temperature, and CO_2 concentrations are explored on tri-trophic interactions with a focus on agriculture pest management. Climate change not just increased the plant biotic stressors but also increased the cost of disease and arthropod pest management because variations resulted in direct effects on the life cycle of arthropods as well as of the pathogen, its epidemiology, virulence, the evolution of new races, host resistance, and finally disease epidemics, complicating pest control. This chapter covers various aspects of climate change in relation to arthropods and plant diseases as well as crop protection strategies used. With appropriate examples, this chapter highlights numerous implications of climate change on arthropod pest and plant pathogens and their repercussions and discusses opportunities to mitigate future crop protection challenges.

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_19

Keywords Warming · Precipitation · Arthropods · Pathogens · Pest control · Host-pathogen interaction · Host-herbivore interaction

1 Introduction

Humans throughout history have been accompanied by changes in daily life, culture, science, technology, agricultural production, and the economy. Also, the agricultural revolution that includes major changes in agriculture production started with civilization, technology, and general human advancement. Global food systems are facing challenges to enhance production to balance between supply and increasing demand (Abbas et al. 2017; Fahad et al. 2017; Gillespie and van den Bold 2017; Saud et al. 2017; Zia et al. 2017; Wezel et al. 2020). As agricultural resources are depleting with increased industrialization and urbanization, producing more from shrinking resources represents a big challenge for humanity (Oerke and Dehne 2004). Human activities are responsible for increasing climatic changes in the world which are influencing the ecology (Karthik et al. 2021; Wang et al. 2021), impacting agro-ecological systems, humans, and food production systems (Roy et al. 2020; Venkatramanan et al. 2020) through rise in temperature and atmospheric concentration of carbon dioxide, heatwaves, intense storms, drought, rainy spells, flooding, etc. (Lobell et al. 2011; Olesen et al. 2011; Amin et al. 2017a, b; Shakeel et al. 2017; Jabran et al. 2017a, b; Mirza et al. 2017). These factors require serious attention as the tendency to yield loss increases under such conditions (Abbas et al. 2014; Patil et al. 2021; Prakash 2021; Zhao et al. 2005). Crop growth and production can be considerably affected due to high temperature, CO_2 concentration, variation in precipitation forms, and presence of plant diseases and will be changed under extreme weather conditions (Chakraborty and Newton 2011; Ghini et al. 2008). About 40% of world's food supply is limited by agricultural pests that under climatic variations and weather disruptions are likely to become more challenging than they were before (Heeb et al. 2019). Droughts, floods, and excessively high or low temperatures can continue to have negative impact on crops such as maize, soybean, wheat, and minor grains, rice, cotton, pasture, and fruits (Aryal et al. 2020). Increases in temperature and CO_2 concentration are creating a great threat of late blight (*Phytophthora infestans*) of potato and blast (*Magnaporthe grisea*) and sheath blight (*Rhizoctonia solani*) of rice (Kobayashi et al. 2006). Life table parameters and trophic relations of arthropod insects are also likely to be modified under climatic variability (Chidawanyika et al. 2019; Rosenzweig et al. 2001) because insects are shown to induce changes in their behavior, physiology, buildup, spread, and geographic range expansion under the influence of climatic variations, altogether complicating pest control (Castex et al. 2018; Nihal 2020). This chapter discusses how climatic variations impact the populations of arthropods, pathogens, and plants and its implications to future pest management complexities.

2 Warming Impacts on Insect Pests

Climatic changes significantly impact arthropods residing in that environment. The crops and herbivores on them may be impacted directly and indirectly by climatic variations. Direct impacts include changes in herbivores' growth, development, reproduction, survival, and dispersal, whereas indirect effects include impacts on relationships between herbivores, the environment, and beneficial biocontrol arthropods through complex food webs (Yadav et al. 2019). Insects being poikilotherms are highly susceptible to thermal surroundings, which means that body temperature of insects shows fluctuations according to thermal surroundings. Indeed, temperature is a key modifier of arthropods biology, growth, development, reproduction, distribution, survival, and beneficial ecosystem services they offer to ecological integrity (Hammad et al. 2017; Gillani et al. 2017; Ahmad et al. 2017; Lehmann et al. 2020). Arthropods have therefore been increasingly assessed for impact by rising temperature in an agro-ecological context since past decades (González-Tokman et al. 2020).

The biological rates (i.e., metabolism) of insects rely on temperature and so do their physiological processes. It has been estimated that a rise of 10 °C may double the metabolic rates of insects (Skendžić et al. 2021), resulting in more consumption or mobility, or rapid completion of metamorphosis, regulating population dynamics, fecundity, population size, survival, and distributional ranges (Bale et al. 2002). Due to the significant correlation of insect population development with increased temperatures, warming is hypothesized to be accompanied by accelerated herbivory and population growth rate changes of insect populations (DeLucia et al. 2008; Deutsch et al. 2018). This suggests that tropical zones, as a result of temperature levels already close to optimum, are most likely to experience decreases in insect growth rates, whereas temperate zone on the other hand is predicted to have escalated insect growth rates as a result of warming (Deutsch et al. 2018). These predictions are likely to implicate grain (wheat, rice, and maize) crop growers as these crops are grown under a variety of climates: wheat which is grown in temperate areas is likely to experience increased pest pressure, whereas pest populations are predicted to reduce on rice as it is grown in tropics, and mix responses are predicted on maize, grown both in tropics and temperate areas (Awis et al. 2017; Nasim et al. 2017; Mahmood et al. 2017; Deutsch et al. 2018).

The above-ground foliage insects are expected to suffer more than soil-dwelling insect arthropods. This is so because the soil is a thermal insulator that protects insects underneath the soil from influence of warming (Bale et al. 2002). As by the end of the current century, the ambient temperature of the earth is projected to increase by 1.8–4 °C (Broadbent et al. 2020; Iyakaremye et al. 2021), and it is expected that populations of some of the global importance pests such as whitefly may increase due to their general dependence on rising temperature and humidity for rapid population growth (Alghabari et al. 2016; Fahad et al. 2016a, b, c; Mubeen et al. 2016; Nasim et al. 2016a, b, c, Broadbent et al. 2020; Pathania et al. 2020). On the other hand, warming leads to reduced response to alarm pheromone in aphids ultimately increasing their vulnerability to natural enemies. Such reduced defense in aphids due to warming have favorable implications for its biological control (Awmack et al. 1997). As insect thermal sensitivity levels are different for different insects because of varied physiological tolerance and narrow ecological niche requirements, the temperature effects are unlikely to cause a uniform increase in pest populations and uniformly impact crop loss economics (Lehmann et al. 2020). Many studies investigating pest insects in the context of warming for their pest severity level have shown a general increase in severity levels in most cases; however, 59% of species are shown to decrease their severity levels as a result of reduced physiological responses (Khawar et al. 2016; Nosheen et al. 2016; Lehmann et al. 2020). In other reports involving 1100 insect species, about 15–37% of species involved were reported to reach extinction by 2050 under prolonged unfavorable conditions (Hance et al. 2007; Thomas et al. 2004). The warming impacts on insect population dynamics can be summarized as increased risks of range expansion, invasiveness, incidence, disease-transmittals, and biocontrol loss.

2.1 Warming Impact on Plant Diseases

The events of disease development, i.e., survival, dispersal, penetration, development, and growth rate of many pathogens, are directly linked to environmental temperature. Temperature and high moisture levels help the pathogen to initiate disease development and germination of fungal spores (Agrios 2005). For several plant pathogenic fungi, moderate temperature is the best for disease development. Late blight of tomato and potato is caused by *Phytophthora* which infect the plant and reproduce rapidly at higher moisture and temperature, i.e., 7–27 °C. For diseases caused by bacteria such as *Burkholderia glumae* and *Acidovorax avenae*, temperature is a vital factor for initiation of disease. So, bacteria can increase growth rate in those areas in which diseases depending on temperature have not been noted yet (Kudela 2009). The spore germination of *Puccinia substriata* increases by increase in temperature (Tapsoba and Wilson 1997). Conidia of *Erysiphe cichoracearum* germinate at low to high temperatures from 7 °C to 32 °C with a high relative humidity of 60–80% (Khan and Khan 1992). Temperature also alters the incidence of other viral and vector-borne diseases. For instance, maize is grown in rainfall areas of the world, attacked by ear rots; the most important fungi are *Fusarium graminearum, F. verticillioides, Aspergillus flavus*, and *A. parasiticus* (Cardwell and Cotty 2002). They produce various types of mycotoxins. The disease is reported to occur in tropics but under suitable conditions may attack anywhere. Surges in temperature might end in a change of distribution of these fungi (Cardwell and Cotty 2002; Probst et al. 2007).

Aphids are easy to survive in mild and warmer winters and transmit *Barley yellow dwarf virus* (BYDV) and also surge viruses of potato and sugar beet (Pandey and Senthil-Kumar 2019; Thomas 1989). Research has reflected that host plants such as wheat and oats become more susceptible to rust diseases with increasing temperature; but some forage plant species become more resistant to fungi with increasing temperature (Coakley et al. 1999).

In case of wheat, spot blotch, caused by the hemibiotroph *Cochliobolus sativus*, is the main chronic disease of warmer wheat-growing areas where relative humidity and night-time temperature are severely affecting poor farming communities in border line lands (Braun et al. 2010; Sharma et al. 2007). This type of environmental conditions occurs in areas of Brazil as well as in the vital rice-wheat system of the eastern Gangetic plains, where the disease is severely due to favorable conditions (Regmi et al. 2002; Sharma and Duveiller 2004; Sharma et al. 2005). In South Asia, the late sown wheat after rice is susceptible to spot blotch in late sown crops due to high temperature during the growth period (Sharma et al. 2007). Under changes in climatic conditions, yield losses in wheat due to spot blotch are projected to increase in South Asia (Sharma et al. 2007); the wheat cultivation areas in South Asia are estimated to decrease in the future (Hodson and White 2007). Yellow rust, for example, has been exposed to adjust to warmer locations (Milus et al. 2009). It is manifested in this case that the wheat areas with increasing temperature will be frequently attacked by the yellow rusts. Breeding for disease resistance against spot blotch of wheat along with good crop management are the main mechanisms of integrated disease management plans (Duveiller and Sharma 2009).

3 CO_2 Impacts on Insect Pests

Insect responds to elevated atmospheric concentrations of CO_2 relative to their distribution, abundance, and herbivory with increases in their consumption, growth, fecundity, and population buildup (Fuhrer 2003) but in a way that is not only highly arthropod species-specific but also depends upon herbivore-plant system (Coviella and Trumble 1999). In response to elevated CO_2 level, the plants are likely to induct changes in physiological responses, such as increased photosynthetic activity accompanied by better growth and high productivity. Such plants with quantitatively and qualitatively better nutritional profiles attract insect pests. With elevated CO_2, the chemical profile of leaves and nutritional value of foliage changes which then modifies herbivory on such affected plants. Such plants accumulate sugar and starch contents in their leaves, resulting in altered carbon/nitrogen ratio (Cotrufo et al. 1998), which resultantly affects palatability and development of insects, which can result from a close link between nitrogen and insect development. In this way, CO_2 shows its impacts on insect consumption and development in some insect groups (Bezemer et al. 1998). The plants with reduced nutritional value may likely be fed more by the herbivore until an equivalent level of food is consumed. This kind of feeding behavior is common in caterpillars, miners, and chewers. The soybean crop that was grown under elevated CO_2 was damaged by the pest arthropods *Popillia japonica* Newman, *Empoasca fabae* Harris, *Epilachna varivestis* Mulsant, *Diabrotica virgifera virgifera* Le Conte, more heavily by a 57% than soybean grown under ambient conditions, probably due to increased level of simple sugars in soybean leaf that then stimulated for compensatory feeding by these herbivores (Hamilton et al. 2005). However, reduced diet quality can also affect the arthropods feeding on them (Lindroth et al. 1993) in a highly species-specific manner, such as thrips may show increases in population size (Bezemer et al. 1998), whereas whiteflies and aphids may show combined effects of either increased population growth or reduced population density (Sutherst et al. 2011). A meta-analysis study that reviewed CO_2 indirect effects on life-history traits of herbivores concluded strong responses of pest insects to elevated CO_2, with a consumption increase of 17%, pest abundance decrease of 22%, development increase of 4%, and relative growth rate decrease of 9% than when under ambient level of CO_2. These effects for chewers were much strong than for sap-feeders (aphids, scales, hoppers) (Stiling and Cornelissen 2007).

3.1 CO_2 Impact on Plant Pathogens and Diseases

The concentrations of CO_2 have a substantial impact on plant diseases (Table 1). Studies interpret that due to elevated CO_2 in the host plant tissues the carbohydrates are produced at a higher level which boosts the development of few diseases like rusts (Manning and Tiedemann 1995). Thick foliage also favors the occurrence of rust, powdery mildew, *Alternaria* blight, *Stemphylium* blight, and anthracnose diseases. Higher CO_2 concentrations persuade greater fungal spore production (Tiedemann and Firsching 2000). On the other hand, due to elevated CO_2, physiological changes of host plants occur that can result in host resistance against pathogens (Coakley et al. 1999). The expression and response of three soybean diseases, i.e., downy mildew (*Peronospora manshurica*), brown spots (*Septoria glycines*), and sudden death syndrome (*Fusarium virguliforme*) due to increased CO_2 varied significantly (Eastburn et al. 2010). Increased CO_2 concentration decreased the susceptibility of barley plants to *Erysiphe graminis* (Hibberd et al. 1996). Overall, the impact of increased CO_2 on plant diseases can be either progressive or adverse, but in most of the cases the disease severity increased (Manning and Tiedemann 1995).

4 Precipitation Impacts on Insect Pests

The precipitation is an important indicator of climate change that affects insect responses. Rainfall patterns are inconsistent; in some events, the frequency of precipitation is decreased, but the intensity is increased or vice versa. This kind of inconsistency leads to weather extremes like droughts, floods, or prolonged stagnation of water which then affects insect species that overwinter in soils by reducing their survival or interfering with diapause. Rain splashes can cause larvae and eggs to wash away from leaf surface during heavy rainfall. Also, small-bodied insects, such as aphids, jassid, whiteflies, etc., may be washed off from plants; hence,

Table 1 Impact of progression of atmospheric CO_2 concentrations on fungal plant diseases

Sr. No.	Disease	Causal organism	Impact on plant diseases	Reference
1.	Root rot of tomato	*Phytophthora parasitica*	Additional CO_2 compensates the negative effect of fungus	Jwa and Walling (2001)
2.	Anthracnose	*Colletotrichum gloeosporioides*	Reduction in disease severity	Chakraborty et al. (2002)
3.	Anthracnose	*Colletotrichum gloeosporioides*	Increase in lesions	Pangga et al. (2004)
4.	Leaf blast	*Pyricularia oryzae*	Increase in susceptibility of rice plants to disease	Kobayashi et al. (2006)
5.	Powdery mildew of *Arabidopsis thaliana*	*Erysiphe cichoracearum*	Increases network of fungal mycelia on developed leaves	Lake and Wade (2009)
6.	Leaf spot diseases of two deciduous trees	*Cercospora spp.*	Increase in disease incidence and severity	McElrone et al. (2010)
7.	Powdery mildew of grapes	*Uncinula necatrix*	No effect on disease	Pugliese et al. (2011)
8.	Downy mildew of grapes	*Plasmopara viticola*	Increase in disease	Gullino et al. (2011)
9.	Rust of beans	*Uromyces appendiculatus*	Increase in disease	Gilardi et al. (2016)
10.	Alternaria leaf spot of cauliflower	*Alternaria spp.*	No effect on disease	Siciliano et al. (2017)
11.	Powdery mildew of wheat	*Blumeria graminis* f. sp. *Tritici*	Decreased severity	Matić et al. (2018)
12.	Alternaria blight of *Brassica*	*Alternaria brassicae*	Decreased severity	Mathur et al. (2018)
13.	Bakanae disease of rice	*Fusarium fujikuroi*	Increase in disease	Matić et al. (2020)

rainfall is a critical factor for insect population development (Pathak et al. 2012; Shrestha 2019). *Agriotes lineatus* L., a soil-dwelling wireworm in grasslands, is a key pest of potatoes, corn, sugar beet, etc. and is highly likely to become more challenging as a result of rapid growth in the upper layer of soil with increased summer rainfall events which is opposite to drought and ambient conditions (Staley et al. 2007). Drought being extreme weather event impacts the insects in versatile ways, such as dry climate creates conditions that are favorable for herbivore growth and development, and some plants under influence of drought are shown to attract more herbivores than plants not under drought influence, mainly because of moisture loss through increased transpiration or decreased production of plant defensive secondary metabolites against herbivores (Yihdego et al. 2019).

5 Effect of Moisture on Plant Diseases

Moisture is another factor to change the patterns and types of plant diseases in developing countries. High temperature along with continuous rains enhanced the *Alternaria* epidemic of apple in Kashmir (Bhat et al. 2015). Regular and extreme rainfall occasions and higher water vapors concentrations help crops to produce healthier and larger cover areas which provide conditions suitable for pathogens and diseases, for example, late blights and vegetable root diseases and powdery mildews (Coakley et al. 1999). High level of atmospheric moisture helps the development of foliar diseases and few soilborne pathogens such as *Phytophthora*, *Pythium*, *R. solani*, *and Sclerotium rolfsii*, whereas drought conditions are effective in the incidence and severity of viruses such as *Maize dwarf mosaic virus* and *Beet yellows virus* (Clover et al. 1999; Olson et al. 1990). In India, the studies revealed that extraordinary rainfall (>300 mm) within a week has been responsible for epidemic of Phytophthora blight of pigeon pea (*Phytophthora drechsleri* f. sp. *cajani*) over the last period (Pande and Sharma 2010; Sharma et al. 2006). In dry hot weather conditions, the populations of *A. flavus* increases which then results in increased aflatoxin contamination of maize. Aflatoxicosis of maize in Kenya in 2004 is a well-known example of this (Lewis et al. 2005; Strosnider et al. 2006).

6 Insect-Plant Interactions in the Context of Agroecology

In this modern era, because of the natural cycles and anthropogenic changes and their impacts on the global environment, plants are affected by excessive radiations, increased temperatures, greenhouse gasses, disturbed precipitation cycles, etc.; hence, the plant defensive systems are altered that can then affect harbored insect population dynamics for their survivals, fecundity and fertility, feeding habits, and dispersal patterns in that plant environment (Table 2) (Karthik et al. 2021). Such environmental changes have vital role in agroecology where the population dynamics of herbivores and their natural enemies are altered due to climatic changes. For instance, it had been noticed that even a small increase in average temperatures (up to 2 °C) can increase winter survival in pink bollworm, *Pectinophora gossypiella* (Saunders), population in cotton fields, ultimately exacerbating the extent of crop losses (Gutierrez et al. 2006). In addition to such direct effects, the raised temperatures indirectly affect pest development by altering the production of secondary plant metabolites in plants (Peddu et al. 2020) as depicted in alfalfa (*Medicago sativa*) where elevated temperatures enhance the production of saponins and sapogenins. Such increase in secondary defensive plant metabolites adversely affect the growth and development of *Spodoptera exigua* harboring alfalfa crops (Dyer et al. 2013). Similar impacts on plant-herbivore interactions are well known due to change in greenhouse gases in the environment. Due to increased CO_2 levels, the plants improve water use efficiencies resulting into bearing higher losses to chewing insect pests (Lindroth et al. 1995); this results into upgradation of the pest status from

Table 2 Ecological impacts of climate changes on significant agricultural and forest pest species due to global warming, greenhouse gas, and altered precipitation patterns

Species	Order: family	Ecological impacts	Reference
Aethina tumida	Coleoptera: Nitidulidae	Invasion and increased geographic spread	Cornelissen et al. (2019)
Agrotis ipsilon	Lepidoptera: Noctuidae	Shift in long distance migratory activities	Zeng et al. (2020)
Bactrocera zonata	Diptera: Tephritidae	Spatial expansion new geographic location, invasion	Tariq (2020)
Bactrocera dorsalis	Diptera: Tephritidae	Geographic expansion and invasion	Qin et al. (2019)
Bemisia tabaci	Hemiptera: Aleyrodidae	Changed pest status due to increased population sizes	Zidon et al. (2016)
Bemisia tabaci	Hemiptera: Aleyrodidae	Range expansion	Gilioli et al. (2014)
Ceratovacuna lanigera	Homoptera: Pemphigidae	Changed pest status	Bade and Ghorpade (2009)
Chilo partellus	Lepidoptera: Crambidae	Host-range expansion, spatial and temporal	Ong'amo et al. (2006), Overholt (2000)
Cicadula sexnotata	Hemiptera: Chalcidoid	Host-range expansion, spatial and temporal	Wang et al. (2021)
Coptotermes formosanus	Isoptera: Rhinotermitidae	Temporal and spatial expansion	Lee et al. (2021)
Cydia pomonella	Lepidoptera: Tortricidae	Improved population dynamics	Luedeling et al. (2011), Stoeckli et al. (2012)
Cydia pomonella	Lepidoptera: Tortricidae	Range expansion	Rafoss and Sæthre (2003)
Eulecanium kuwanai	Hemiptera: Coccidae	Host-range expansion, spatial and temporal	Wang et al. (2021)
Gryllidae spp.	Orthoptera: Gryllidae	Increased incidence, changed pest status	Chailleux et al. (2021)
Gryllotalpa orientalis	Orthoptera: Gryllotalpidae	Host-range expansion, spatial and temporal	Wang et al. (2021)
Helicoverpa armigera	Lepidoptera: Noctuidae	Host-range expansion and improved population dynamics	Keszthelyi et al. (2013), Kriticos et al. (2015)
Helicoverpa zea	Lepidoptera: Noctuidae	Increased incidence, changed pest status	Ajayi and Samuel-Foo (2021)
Hyposidra talaca	Lepidoptera: Geometridae	Changed pest status due to short developmental period and increased voltinism	Roy et al. (2020)
Kytorhinus immixtus	Coleoptera: Chrysomelidae	Host-range expansion, spatial and temporal	Wang et al. (2021)
Locusta migratoria	Orthoptera: Acrididae	Host confinement	Tian et al. (2011)

(continued)

Table 2 (continued)

Species	Order: family	Ecological impacts	Reference
Lycorma delicatula	Hemiptera: Fulgoridae	Host-range expansion, spatial and temporal	Wang et al. (2021)
Lymantria monacha	Lepidoptera: Lymantriidae	Geographic expansion and improved voltinism due to shorter lifecycles	Melin et al. (2020)
Myzus persicae	Hemiptera: Aphididae	Changed trophic interactions with associates and reduced lifecycle	Harrington et al. (2007)
Oligonychus coffeae	Acari: Tetranychidae	Short developmental periods	Saren et al. (2015)
Operophtera brumata	Lepidoptera: Geometridae	Changed trophic interactions with associates	Jepsen et al. (2013)
Oxycetonia versicolor	Coleoptera: Scarabaeidae	Changed pest status and increased incidences	Daravath et al. (2020)
Phloeomyzus passerinii	Aphididae: Phloeomyzinae	Host expansion, changed pest status	Pointeau et al. (2021)
Plutella xylostella	Lepidoptera: Plutellidae	Changed pest status	Marchioro and Foerster (2012)
Spodoptera litura	Lepidoptera: Noctuidae	Changed pest status	Kranthi et al. (2009)
Thaumetopoea pityocampa	Lepidoptera: Notodontidae	Changed trophic interactions with associates	Stastny et al. (2006)
Tuta absoluta	Lepidoptera: Gelechiidae	Spatial expansion new geographic location, invasion	Abdul-Rassoul (2014)

secondary to primary pest. This has been noticed in the case of *Spodoptera litura* Fabricius and *Helicoverpa armigera* (Hübner) which had become a major pest in the crops grown under increased CO_2 concentrations (Kranthi et al. 2009). Another significant change in pest ecology due to climatic change can be noticed by observing the change in ecological outbreaks of desert locust (*Schistocerca gregaria*, Forskål, 1775) whose spread is significantly favored by increased temperature and precipitation in desert regions. Such changes have serious implications for the global food supply and food security. Hence, understanding the changing ecologies due to climatic shifts is vital. Here, we try to elaborate on the impact of perpetual environmental shifts in agro-ecological systems with an emphasis on insect – plant and host-pathogen trophic interactions and pest status of significant species.

6.1 Climate Change and Semiochemical-Based Tri-trophic Interactions

Insects and plant interactions are influenced by environmental change and outrageous climate occasions. The ecological interaction among plants, herbivore, and their natural enemies are interacting with each other, and such relations can vary on the continuum of trophic associations ranging from antagonism to mutualism. Climatic factors are the major governing agents of such a significant interaction, and even some minor shifts in these factors can alter the prevailing equilibriums (Giron et al. 2018; Moore and Allard 2008). It has been a fact that the plants interact with other biotic players including herbivores, parasites, and predators by activating their metabolic responses (Giron et al. 2018). In a typical tri-trophic association, plants-produced volatiles (Karthik et al. 2021) are sensed by the foraging herbivores to locate their plant host (Giron et al. 2013), while at the same time the natural enemies used those very volatiles to predict the presence of their preys (Endara et al. 2017). That is the reason some of the integrated pest management (IPM) practices and programs focus on manipulating such cues to support natural biocontrol functions.

The climatic changes resulting from increased temperature, altered humidity, CO_2 concentrations in the atmosphere, soil pollution, and changed fertility under prolonged influence of environmental stresses can hinder plants' ability to produce such metabolites and semiochemicals (Boullis et al. 2016). For instance, extended reduction in mean nocturnal temperatures results in increased production and accumulation of phenolic and rutin compounds in tomatoes (Bradfield and Stamp 2004) as well as reductions in polyphenol oxidase (PPO) (Rivero et al. 2003) and protease inhibitor activities (Green and Ryan 1973). In turn, having proven adaptive capacities, the insects perceive the changing plant physiologies and metabolomics to alter their ecological associations with new hosts or even to expand their foraging landscapes (Fordyce 2010).

6.2 Herbivore – Plant Population Asynchronization Under Changing Climate

As long as the success of insect pests and their natural enemy's population is concerned, the synchronization of their fecundities with the availability of the host resource is vital (Harrington et al. 1999). If the oviposition isn't timed with the onset of new leaves, as in the case of forest pests harboring on deciduous trees, the resulting population will have a greater chance of starving to death. The major change in phenological relations between insect and their plant hosts can be a common result of environmental shifts in agro-ecosystems (Singer and Parmesan 2010). For example, an increased mean temperature is reported to cause increases in leaf thickness and numbers of trichomes (small hair or other outgrowth from the epidermis of a plant). This change will hinder the population development of whitefly in the tomato crop (Bickford 2016). Not only the herbivores are affected by this asynchrony, but the next trophic level in the food chain that consists of the natural enemies (Wetherington et al. 2017) and also some of the pollinators (Minckley et al. 1994) of the crop have to adjust their life cycles accordingly (Price 1973). This requires plenty of adjustments in the development cycles of the insects (Price 1973).

6.3 Effect of Climatic Conditions Changes on Vector-Borne Diseases

Plant viruses work in association with their vectors and host plants. The climatic needs of diseases and their vectors limit the danger of their spread at the local and regional level. The populations of insect vector and host plants are affected by changing climate and spread of viruses (Dukes et al. 2009). The primary infection in the host, the propagation of the pathogen inside the host, and the horizontal transmission of the virus to additional hosts by the vector are all affected by global warming. The physiology of host plant is altered by climatic changes, so it may affect its compatibility with vector, disease susceptibility, and vector transmission. Change in climate has adverse effects on insect vector, i.e., density, vector phenology, migration, overwintering, and its stability. Increased CO_2 levels have a little impact on insect herbivores. The size and composition of insect prey populations indirectly have influence on the third trophic level by higher CO_2 level. Climate change may cause changes in the population of either the host plant or the insect vector that spreads plant viruses (Canto et al. 2009).

7 Spatial and Temporal Adjustments in Insect Pests Due to Climate Change

Some species may shorten their average lifecycles to synchronize with the availability of their host or as per the ambient temperature range for maximum population growth. According to estimates, an average of at least 4 °C temperature will rise by the end of this century (Brown and Caldeira 2017) which will have serious implications in altering plant growth patterns with shifts in sowing dates for major crops, which will likely shift pest and pollinator populations to different temporal windows (Table 2).

Confinement of some insect species to specific areas is actually due to their adjusted environmental tolerance and their strong association with the host plants for habitation (Rosenzweig et al. 2007). The environmental shifts as discussed earlier is now pushing the pest out of their normal habitats to explore new niches as elaborated by different reports about range shifts among insect pest species from lower altitudes to higher altitudes, from one cropping system to another and invading new geographic locations and establishing there (Table 2) (Hansen et al. 2012; Jepsen et al. 2008; Jones et al. 2017; Raffa et al. 2008; Roy et al. 2020). Even if the pest doesn't change their locations, their pest status gets altered (Estay et al. 2009) rendering several minor pests to become the major insect pest species in the same agroecosystem (Jones et al. 2017; Roy et al. 2020). Many reports have demonstrated how changing global temperatures and precipitations are altering the status of many agricultural pest species by affecting their population dynamics in a particular habitat (Estay et al. 2009).

Such temporal and spatial shifts in herbivore and predator dynamics can be attributed to altered plant metabolomics that may make an unpalatable host suitable to an invasive species or vice versa (Chailleux et al. 2021; Pureswaran et al. 2018). This phenomenon has been reported recently in forest ecosystems (Pureswaran et al. 2018) where *Dendroctonus ponderosae* Hopkins, the mountain pine beetle, has been seen to be shifting toward new forests of an unexplored host pine tree, *Pinus contorta* (Cudmore et al. 2010).

8 Climate Change-Associated Reduction in Pesticide Sensitivity

Extensive agriculture wants farming methods to be improved to meet ever-increasing world food demand through increasing both the rate of crop production and protection against insect pest attacks (Lamichhane et al. 2015). Use of chemical insecticides has been a most frequently used pest management strategy worldwide to keep the pest below economic injury levels. Where on one hand, this frequent and indiscriminate usage of the synthetic pesticides has led to natural resistance development in the target pest species due to exerting natural selection pressures; the changing environmental conditions, on the other hand, may also result into conditional resistance development (Matzrafi 2019) either by reducing chemical efficacy or by decreasing pest susceptibility levels. Since the efficacy of insecticides applied significantly depends upon prevailing environmental conditions (Benelli et al. 2021; Koleva and Schneider 2009; Wiwanitkit 2013), a change in temperature, relative humidity, and CO_2 concentrations can alter pesticide residual effects (Ficklin et al. 2010), translocation potential of the applied chemicals (Matzrafi 2019), crop coverage after application, and shelf-life of the pesticides, ultimately resulting into the reduction of pesticide efficacy. The reduction in pesticide sensitivity due to altered climatic conditions change in plant physiology under altered CO_2 levels (Dyer et al. 2013) and adjustments in pest lifecycles lead toward conditional resistance development in major agricultural pests (Gutierrez et al. 2008). For example, the elevated CO_2 in environment can even reduce the resistance of *Bt* rice varieties against brown plant hopper, *Nilaparvata lugens* (Stål), and even the application of triazophos was not as efficient as expected due to rapid degradation of the pesticide molecules under elevated CO_2 levels (Ge et al. 2013). Similar patterns of rapid degradation of chlorpyrifos has been reported in paddy fields where elevated CO_2 levels persisted in climate (Adak et al. 2016). Such induced resistance in the insect pests can be attributed to the altered physiological and biochemical compositions in plant systems (Pritchard et al. 1999), and such changes may include, but not limited to, photosynthetic efficiencies, altered C:N rations, altered free amino acid availability, and the concentration of secondary plant metabolites (Liu et al. 2003) due to elevated CO_2 concentrations in the environment (dos Santos Kretzschmar et al. 2009).

Rise in average temperatures due to global warming can have a serious implications in terms of herbicide usage, as it has been reported that herbicidal efficiency of paraquat, glyphosate, glufosinate, dicamba, 2,4-D, and diclofop-methyl significantly decreases due to increased temperatures (Ganie et al. 2017; Godar et al. 2015; Lasat et al. 1996; Mahan et al. 2006; Matzrafi et al. 2016). These anomalies in herbicide effectiveness can be attributed to the altered leaf characteristics of the weeds such as altered wax glazing (Hess and Falk 1990) or reduced penetration and translocation of the systemic herbicides (Currier and Dybing 1959) due to increased temperatures during their growth periods (Ganie et al. 2017). Therefore, it is highly desirable to direct future inspirations toward discovery of more potent adjuvants and active molecules that are tolerant to such environmental changes.

9 Challenges and Opportunities in the Management Insect Pests in Climate Change

9.1 Need for the Region-Based Research

Parameters to determine the impact of the climate change on the biology of the pests can vary for tropics and temperate regions; therefore, research should be based on regional characteristics. In the tropics, increase in temperature due to climate change may reach to lethal limit of some species; therefore, such parameters need special considerations in these regions. In the countries like Australia where mild winters occur, the drought and wind can be the important factors needed to explore for insect pest interactions particularly to predict insect pest outbreaks. However, in countries like Canada where harsh winters persist, mortality factors and pest survival are unique parameters to be studied (Juroszek and Von Tiedemann 2013). Although this presents the broader overview for the region-wise research, but in point of fact, every agro-ecosystem needs research at micro- and macrolevel to address the issue.

9.2 Response of Farmers to Pest Problems Due to Climate Change

Adoption of the sustainable pest management strategies is slow in response to climate change. Only transition observed in this respect has been increasing the numbers of insecticide applications by the growers per cropping season. Increasing the quantities of the chemicals to manage pests will in turn result into increased risk of resistance in pests, nontarget effects, residues in food, and loss of the biodiversity (Ziska 2014). There is thus a dire need to reduce losses in the yield due to insect pests while restoring and ensuring prolonged sustainability of ecosystem services (biological control agents and pollinators) by lessening adverse environmental impacts from climate variables (Heeb et al. 2019).

9.3 Severity of Climate Change in Developing Countries

Developing countries (particularly South Asia) are likely to be more suffered as their majority populations are principally dependent upon agrarian-based economies. This situation gives rise to important challenges with respect to their social, economic, and agricultural production systems (Mirza 2011). The World Bank has also assessed that people with limited resources in the Asian countries will suffer more as their sources of earnings are substantially dependent on climate. Therefore, these farmers will be directly affected with the change in the climate (Bank 2009). Frequent extreme weather events like heavy rains and floods in the last 10–15 years in India and Pakistan are directly associated with climate change (Ali and Erenstein 2017).

9.4 Mitigating Climate Change from Farm Level to Policies at Government Level

There are several factors which can affect adoption of the practices to mitigate climate change. Fundamentals are lack of knowledge about deleterious effects on crops, small holdings, and less availability of the financial resources to adopt novel technologies mitigating environmental impacts (Abid et al. 2016). Moreover, majority of the farmers are unaware of management practices to cope with climate change. Practices like crop diversification and changing timing of operations can be helpful at farm and landscape level in reducing effects of climate change by desynchronizing host-pest phenological association, enhancing biological control agents and other ecosystem services. However, awareness about such benefits is needed for the growers; otherwise, it will be difficult for them to adopt new technologies.

Effective extension services should be provided to the farming community to educate them with challenges from climate change and possible solutions to prevent or at least minimize the risk. Even in the current scenario, extension systems have limitations like lack of financial resources and coordination among the various stakeholders. Intensive coordination is needed among the extension staff, researchers, and those who are responsible to support the farmers. Extension staff is needed to be equipped to the extent that they must have quantitative evidence on how the adoption of pest management at farm and landscape level will impact crop yields (Harvey et al. 2014).

Research required to meet the needs of the region is an important prerequisite to mitigate climate change challenges. However, there are several constraints that impede developmental research including lack of sufficient financial resources and adequate expertise of scientists, collaboration, and coordination at regional, national, and international levels and connection with the extension experts. International organizations can play an important role to cope these problems by providing adequate funding for high-quality research and capacity building concerned scientific community in developing countries. Finally, this developmental research should reach to the stakeholders out of the boundaries of the literature (Heeb et al. 2019).

Exploring the role of crop diversification and impact of altering the time of the various operations, breeding for insect pest-resistant varieties and various water management practices are the important research areas at regional level to mitigate climate change. Efficacy of the insecticides is strongly dependent upon the environmental conditions; therefore, increase in temperature and CO_2 concentrations can affect population reductions after chemical applications. Conditional resistance which is the change in the pesticide efficacy may occur in insect pests by epigenetic changes due to environmental changes. Hence, biochemical, physiological, and transcriptional components involved in conditional resistance are necessary to be investigated for the development of long-term future pest management programs (Matzrafi 2019).

Another responsibility of the researchers is to provide clear policy to the government, so that regulatory authorities should implement and inform all the stakeholders. These policies should take into account of the regional needs and impediments for adoption and mitigation of the problems related to the climate change. However, as mentioned earlier, regulatory authorities in developing countries have financial constraints for proper functioning, coordination, and knowledge transfer (Heeb et al. 2019).

9.5 International Collaborations

9.5.1 Invasive Species Management

The invasive species may behave differently in the climate change. Introduction, establishment, impact, distribution, and effectiveness of management strategies of new invasive species will be altered with the change of the climate in the future. The problems with the invasive species are immediate and intense. These above said aspects provide points to begin the research. However, research on these aspects will take a long time in international coordination and resources, but time to provide guidelines for the sensible management of the consequences is quite short (Hellmann et al. 2008).

9.5.2 Management of Migratory Insect Pests

Progressive increase in the temperature is affecting phenologies, geographical distribution, and spatiotemporal dynamics of the migratory agricultural pests as proved for *Agrotis ipsilon* (Hufnagel) in China. Due to increases in temperature, migratory adults of *A. ipsilon* reach to the peak 8–17 days earlier, and show enhanced potential of north word shift of overwintering in the range of >200 km and also with an expansion of migratory range of more than 700 km. These findings suggest the need to develop forecast systems and long-term pest management plans to meet these challenges in the face of changing climate (Zeng et al. 2020). As such insect pest species can travel into the neighboring countries through boarders, therefore, coordination will be needed among the countries for such species.

9.6 Disease Management Practices and Future Prospects

- The permanent venture in the monitoring of the environment is needed.
- More coherent attitudes are needed to be taken to ascertain the actual mechanisms of impact of climatic changes on plant diseases.
- The techniques for breeding the disease-resistant varieties of plants are ranked at the top to mitigate the problems posed by the changing environmental conditions. It will address the present and the future problems.
- Capacity building of all the stakeholders including scientists, farmers, agricultural consultants, and policy makers regarding the epidemiological perceptions, climate prediction models, and better crop husbandry is the need of the hour. Their collaborative efforts will lead to useful management strategies of the problems.

10 Conclusion

Conclusively, climate change can result in outbreaks of new pests with establishments of unique tri-trophic interactions or disrupt existing species equilibrium by altering the ecological dependence of multiple species in a food web. With the pace with which global environments are deteriorating, tremendous impacts of increased urbanization in our agroecological and forest systems can be predicted. Such effects in our agroecosystem will likely generate risks for biodiversity and ecosystem, and changes in demand and supply of culinary commodities, global warming, excessive deforestation as a result of quick tree decline, severe pest attacks, and reduced pollination services as a result of stressed pollinator populations are just a few to name. International cooperation in integrating data and modelling the population response will help in tailoring IPM strategies to altered climates to effectively respond to future challenges from climate change.

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Climate Change Effects on the Quality of Different Crop Plants and Coping Mechanisms

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Abstract Climate change is a worldwide issue influencing the quality and production of many important crops. A few variables (including concentration of CO2), extraordinary temperature occasions, unexpected precipitation, and altered ocean level are significant reasons of environmental change situation. To forecast general effect of climate change, there ought to be appropriate focus on climatic variables and their impacts. Total world populace is supposed to reach around 30% up to 2050. To fulfill the rising need of food for increasing populace, increased output along with better quality food can be a mitigation methodology. All elements of climate influence the quality along with quantity of commercial output in vital crops. Elevated atmospheric carbon dioxide content enhance wheat's amylose and grain output yet diminishes polypeptide and bread characteristics of wheat grain, but drought episodes along with elevated temperatures expand the amount of polypeptide in grains of cereal. Elevated carbon dioxide content is related with enhanced grain whiteness and firmness in rice. Fiber content and quality and quality of fodder were likewise observed to be adversely impacted by the climatic elements. Increased amount of oleic acid along with oil but diminished saturated fatty acid along with linoleic acid in elevated temperature system has been described. The adverse consequence upon quality characteristics has been seen in light of unfavorable climatic circumstances that are anticipated to be more regrettable during upcoming ages toward battling with the misfortunes; an integrated methodology of the management procedures as well as breeding strategies could be possibly used that can guarantee the food production. Appropriate manure application, good management of crops, and usage of sound cultivars can be useful in decrease of yield as well as quality misfortunes because of environmental change.

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_20

Keywords Climate change · Nutritional value · Cereals · Oilseed · Cotton · Forage · orticultural crops

1 Introduction

Climate can be named as pervasiveness of general weather condition on a particular area over an extensive stretch of time (even hundreds of years), while weather condition is a momentary variation. Natural variation happening, related to these climatic patterns, are named as climate change. The extended modification in worldwide normal mean warmth would be prone to ascend over the range of 0.3–0.7 °C for the time of 2016–2035 comparative with the reference time of 1986–2005. Rise in temperature in various nations by 2050 is shown in Table 1. Change in climate is expected to diminish sustainable ground and surface water fundamentally in arid subtropical regions (Kirtman et al. 2013; Jiménez Cisneros et al. 2014). A few elements are enhanced while a few different variables decline because of environmental change. These elements are temperature of troposphere, humidity, oceans temperature, ocean heat and level, land's temperature that will generally rise whereas glacial masses, ocean snow and ice sheet that will often diminish.

Global warming is exceptionally related to change in climate, and greenhouse gas is likewise corresponding for them as it contributed mainly to increasing earth's temperature as sunlight energy is captured by climatic gases. Such gases comprise methane (CH_4), perfluorocarbons (PFCs), nitrous oxide (N_2O), carbon dioxide (CO_2), sulfur hexafluoride (SF_6), and hydrofluorocarbons (HFCs). The peculiarity of GHG till a specific cutoff is existence empowering since it tends the globe moderately hot, practical for living. Devoid of greenhouse impacts, the entire warmth might get away returning to space and putting the globe in the icy cold. Generally, 80% of carbon dioxide in the world's climate is accumulated from developed nations. Likewise, the USA is the world's biggest donor toward GHG. Developed nations are radiating bigger extent of GHG. Marine industry has likewise contributed its part to the global warming. Ships emitting sulfur account for GHG. NASA reorganized the data about articulated expansion in CO2 discharge from 2000 to 2011.

Table 1 Rise in warmth in various nations up to 2050

Authors	Nations	Raising temperature in (°Celsius)
(1998) Sanghi	Brazil	2.0
(2006) Cap and Lozanoff	Argentina	2.0–3.0
(2006) Timmins	India	2.0–4.0
(2007) Velasco González	Chile	2.5–5.0
(2007) Mendelsohn and Seo	South America	1.9–5.0

This environmental change will ultimately cause disturbance of sea flow, increased desertification, change in agrarian production, water deficiency, increase in devastating storms, outrageous climates, increased air contamination, increase energy necessity for cooling reason, loss of animal and plant species, plant and animal habitat loss, lasting loss of icy masses, death because of heat waves, acid rains, and permafrost melting (Rocha et al. 2022). Aside from large number of negativities, environmental change likewise has a few advantageous impacts; for example, because of increased temperature, less energy is expected for warming system, frozen areas of the earth may experience good plant development and milder environments, there will be a decline in number of mortalities because of chilly climate, and it might lengthen the crop development period which would increment agricultural efficiency; correspondingly, expansion in CO_2 might improve the production and so on.

Environmental change has really moved us toward natural change that is lost. Ascend in ocean level is driving the sea framework toward amazing condition. Climatic change is related with outrageous weather condition that could influence agronomy essentially like dry season, extreme precipitation, high melting rate of cyclone, and glaciers (shaped because of high temperature and evaporation rate of water) (Rocha et al. 2022). Agricultural production up till present has significantly been impacted in terms of the amount and nature of economic produce, and widespread starvation is supposed to be severe in upcoming years. Pakistan is encountering the danger of floods because of high, extraordinary, and erratic precipitation pattern.

2 Effect of Changing Climate on Agriculture

Change in climate is significantly affecting the circumstances in which agronomic activities are performed (Arunanondchai et al. 2018). Environmental change (rainfall, temperature, ocean level, and so forth) can influence agricultural efficiency and soil-water balance, and its fundamental reason is GHG discharge. Agriculture sector contributes in environmental change with discharge of CO_2, nitrous oxide, and methane and is impacted by it. The portion of agriculture in environmental change can be limited using better agronomic practices, for example, CH_4 delivery can be decreased through appropriate administration of paddy field (Sun et al. 2020), utilization of zero culturing, mulching, and better cultivars (Kristiansen et al. 2021). Livestock contributes almost 80% of methane discharge, and this contribution can be diminished through proper diet of animals, as well as the by their waste management (Naz et al. 2022; Masood et al. 2022).

Agriculture is seriously impacted by climate which at last affects agronomic efficiency (Fig. 1). Environment of a region decides that region's vegetation. Raising average temperature reduces the duration of various crops driving to less production. Aforementioned changing temperature brings about occurrence of pests along with disease that additionally decreases yield (Mora et al. 2022). Fluctuation in

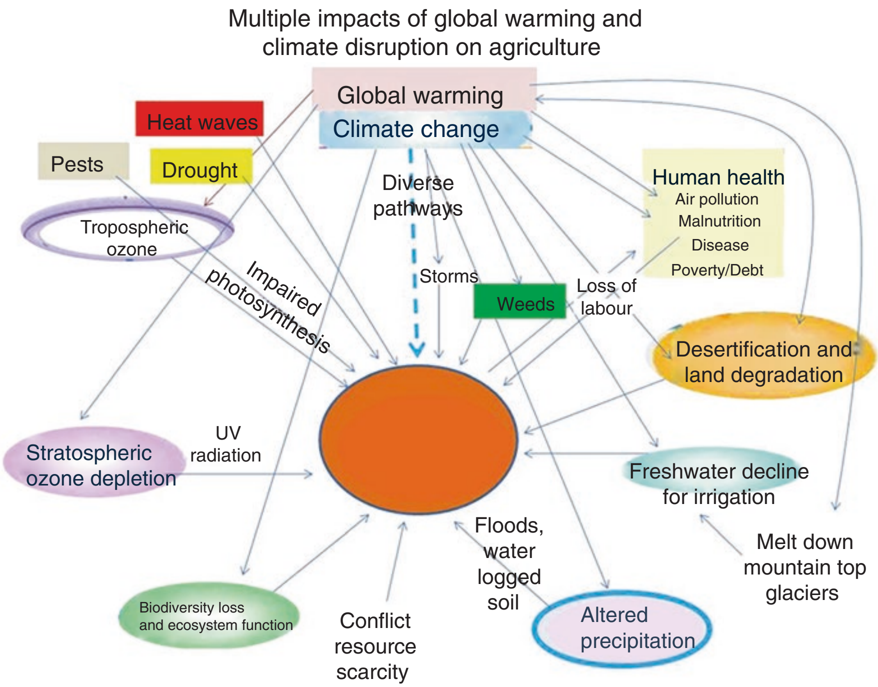

Fig. 1. Various results of changing climate and global warming on yield of agriculture. (Resource: Eco-generation's Resources)

precipitation and temperature essentially affects agrarian production. The precipitation doesn't influence the productivity, yet temperature impact is more conspicuous (Mahato 2014).

The impacts of changing climate on agronomy differ as per latitude change. Crop yield is harmfully affected in various regions after variation in climate, whereas in others it is improved. It is projected that on worldwide basis, this reduction as well as increase in agriculture production will not vary significantly in the upcoming years, but important changes in recent status will be possible in low latitude regions, as well as the economic losses due to increasing temperature will be above that of doubling of CO_2 (Mendelsohn 2007; Akram et al. 2022a, b; Din et al. 2022).

Climate change has negative influence on quality and growth of numerous crops (Ahmad et al. 2021). Multiplicative stage is extremely vital in plant's growth phase; for example, it is a cause of production. Drought strain in the course of grain filling periods has numerous calamitous consequences on the wheat crop's production as linked to initial phase strain contact (Singh et al. 2007).

Worldwide change in temperature has a devastating impact on agriculture production. Poor seed setting and pollen sterility due to heat stress has been stated in several field crops. According to Teixeira et al. (2013), four main harvests (rice, wheat and maize) are susceptible to enhanced worldwide warmth particularly in various regions of Asia and America. Reasonable elevated temperature causes cell damage and occasionally cell death to take place (Ahmed et al. 2022).

3 Climatical Change and Cereal Crops Quality

Cereals represent 90% of dietary essentials of total populace. Rice and wheat are two significant grain crops around the world. Corn is the third greatest significant food next to rice and wheat. Wheat is principal food in Pakistan, Argentina, China, India, and Turkey although rice is basic diet in Japan, Bangladesh, China, and Taiwan. Maize and leguminous plants are a few other significant cereals. Present situation of environmental alteration and the situation effects on output along with nature of cereals are vital to consider guaranteeing supportability in financial produce.

High temperature, raised CO2 fixation, chilling, and unpredicted precipitation design are a few vital climatic occasions influencing the nature of grain crops. The percentage decrease in yield of a few harvests with expansion in temperature is shown in Table 2.

Elevated carbon dioxide mainly influences the nutritional along with chemical structure in the grain. Raised carbon dioxide is related with increasing heat waves; these two influence the efficiency along with grain properties in significant farm crops. Carbon dioxide fixation in air is increasing step by step projected to be between 470 and 570 umol/mol by 2050 (IPCC 2007).

Yields of wheat are to a great extent impacted by increased degree of CO2. Physiological irregularities because of raised CO2 in climate incorporate diminished 1000-seed weight because of unusual seed advancement system. 2010 Elevated carbon dioxide prompted quick vegetative development in rice, and expanded seed yield had been additionally noticed.

Elevated carbon dioxide came about in expanded amount of amylose to the detriment of amylopectin protein (and 0.9–7.6% expanded wheat starch (Uprety et al. 2010). Darmatta et al. 2010 stated starch gathering in granule of wheat due to elevated warmth. Wx quality in rice (related with increased amount of amylose and mineral and protein substance) was affected through expanded carbon dioxide levels, making rice cooking troublesome. Elevated warmth adversely affects fragrance and amylose content of rice. Low temperature is related with high amylose content

Table 2 Percentage decrease in output of numerous crops due elevated warmth

Crops	1 °C	2 °C	3 °C
Wheat	8.1	18.7	25.7
Rice	5.4	7.4	25.4
Maize	10.4	14.6	21.4
Groundnut	8.7	23.2	36.2

as well as great cooking quality of rice (Uprety et al. 2010; Hussain et al. 2022a, b; Waleed et al. 2022).

Twenty-three percent decrease in grain weight, differed concentration of gluten, and consistent amylose content in wheat were found under high temperatures. Critical temperature at grain filling of wheat was found to be 12–22 °C. High temperature is related with accumulation of heat units, resulting in diminished period of growth. Shortened grain filling period under increased heat was cited by Farooq et al. (2011). Biochemical and physiological study of crop types under CO_2-increased conditions, for example, (Free Air CO_2 Enrichment and open-top chambers, as well as high temperature system showed diminished carbohydrate content in soybean seed.

Biochemical changes comprise diminished nitrogen content, stimulus for photosynthesis, diminished activities of genes of rubisco, and photosynthesis (Nagarajana et al. 2010). Enhanced protein yield, yet low zeleny content under high CO2, was mentioned by Pikki et al. (2007). Kimball et al. (2001) announced 3.9–14.1% decrease in protein content; it depended on rooting capacity of plant species. Different response of lysine content against expanded CO2 relies on the CO2 level intensity and was found to be most noteworthy in open-top chambers (OTC).

Handling quality in wheat is a significant characteristic and profoundly connected with lipid content and binding capacity of protein. CO2 fundamentally affects gluten and lipid content in wheat by its indirect effect on dough flexibility and extensibility. Uprety et al. (2010) showed adverse consequence of CO2 on glutelin and gliadin, and these two have the role with the upkeep of dough properties. Diploid, tetraploid, and hexaploid wheat were compared for grain investigation under FACE (Free Air CO2 Improvement) by Uprety et al. (2009). The conclusion was that grain morphology in hexaploid wheat was affected more than diploid and tetraploid.

High CO2 is related with high temperature that prompted expanded transportation of amino acid to sink (leaves); decreased amino acid in grains caused low handling and baking quality of wheat. Effect of CO2 on grain whiteness in rice was accounted for by (Terao et al. 2005). Rice is easily affected to high-temperature stress during the development of panicle and meiosis causing inconsistent pollen development and outright sterility. Production of rice, particularly rain-fed rice, is in danger because of successive dry season and diminishing diurnal temperature range. Stress-tolerant varieties of rice needing less water and thriving at high temperature ought to be developed. Research on rescheduling calendar of crop and cropping pattern is important to relieve the antagonistic climatic circumstances (Uprety et al. 2010).

Adverse consequence for crops has been forecasted in light of expanding CO2 fixation in air. To forecast effect of environmental change, there ought to be legitimate figuring out about climatic variables. Proper fertilizer application, crop management practices, and utilization of appropriate cultivars can be useful in combating with rising climatic issues.

3.1 Impact of Changing Climate on the Quality of Oilseed Crops

Oil production in Pakistan is insufficient. Only 30% of the country's oil requirements are fulfilled regionally; the remaining 70% are imported. Sunflower is the fourth most significant oilseeds crop, providing around 36–50% of oil production (Rauf et al. 2017). However, the grain quality and yield of sunflowers can adversely be affected by heat stress (Kalyar et al. 2014; Niazi et al. 2014; Khan et al. 2016).

The composition of fatty acids determines enzymatic activity inside the plant. Enzymes consist of protein naturally; therefore, they require optimum temperature (37 °C) for appropriate functioning.

The oil production from oilseed crops ranges between 45% and 50% based on fertilizer, seed variety, and climatic conditions. The amount of oilseed rape and the ratio of saturated, polyunsaturated, and mono-unsaturated fatty acids all are significantly influenced by temperature. Research indicates that heat and cold may impact the composition of fatty acid in oilseed rape, particularly the amount of linolenic acid (Wójtowicz and Wójtowicz 2020). Climate changes have posed a significant challenge to sunflower production and yield. Although sunflowers have deep taproots that allow them to absorb water from the soil during droughts, they require less rainfall to grow than other cereal crops. Simultaneously, crop rotation and the irrigation system can more effectively improve sunflower production (Adeleke and Babalola 2020).

Khan et al. (2016) conducted an experiment to assess seed yield and oil content percentage under heat stress conditions. Both characteristics depended on cell membrane integrity (CMI) and pollen viability (PV). The percentage of cell membrane integrity, which determines the viability of pollen, has been drastically lowered by high temperatures (Khan et al. 2016). According to Onemli (2012a), an experiment for fatty acid and seed oil analysis was conducted by considering different climatic factors, for example, humidity, precipitation, and high and low temperature. After collecting 2 years of data, the second year showed a relatively high-temperature variation, a decrease in oil content of 6.74%, and an increase in oleic acid at the detriment of linoleic acid.

Izquierdo et al. (2013) stated that the composition of fatty acids (FA), including oleic and stearic, was due to extreme night temperatures. However, palmitic acid contents were not changed due to the high temperature. Early sowing condensed palmitic acid and oleic acid concentrations. Therefore, stearic acid and linoleic acid increased at early sowing dates. Climate change can decrease the resources availability and alter the factors which are essential for oilseed plant growth and yield, causing phenotypic changes that are caused by the environment (Jaradat 2016). Fatty acid composition in relevance to climate change in peanuts was analyzed by Onemli (2012b). After collecting 3 years of data, an increase in percentage of oleic acid and decrease in linoleic acid percentage and reduced saturated fatty acid content with each passing year was reported. Genotype X environment was the most crucial factor in predicting peanut oil quality.

Oil composition and content are highly affected by high temperatures and rising CO_2 content in the atmosphere (Onemli 2012b). Oilseed crops are projected to be at maximum hazard as worldwide temperature and CO_2 concentration is expected to increase in the future. To maintain the oil quality, composition of fatty acid, as well as oil concentration of the seed, a dynamic strategy is essential to consider the methods to control the conditions causing climate change.

3.2 Impact of Changing Climate on the Quality of Cotton Crop

The world's most significant cash crop and a source of raw materials for the textile industry is cotton. In a developing country Pakistan, cotton has a 5.1% contribution in agriculture as well as 1% of GDP. During 2015–2016, cotton production reduced due to change in precipitation patterns, high insect, and disease infestation (GOP 2016). In 2000, there were 1.83 million tons of cotton produced, while, in 2019, it was just 1.56 million tons. Since cotton employs the largest workforce, the crops' highly inadequate growth performance is a significant concern. The productivity growth of critical crops could be affected by the rising average annual temperature change, which could also affect Pakistan's food security (Abbas 2022). Chemical constitution changes due to the depolymerization of cellulose in fiber result in degraded fiber quality (van der Sluijs and Long 2016).

The growth and production of the cotton crop may be affected by temperature and precipitation changes. According to reports, the appropriate temperature for optimal growth of cotton is 33 °C. In contrast, significant decreases in boll retention and flower have been observed over 36 °C (Habib-ur-Rahman et al. 2018). In Pakistan, climate change adversely affects cotton crops due to intensive fertilizer, pesticide applications, and excessive irrigation water (Imran et al. 2018).

Crop phenology (phases and stages) is often expressed in the accumulation of growing degree days. The local meteorological conditions influence crop phenology. It affects various aspects of crop management, such as selection of cultivar and alterations in sowing dates (Abbas et al. 2017). Economically significant factors that affect are height at the flowing stage, the weight of cotton stalk, yield of cotton seed, and lint percentage (yield indices). Cotton seed production and plant height were discovered to have a significant positive association. Therefore, identifying the changes in cotton stalk and plant height and reaction toward climate change is essential for management of cotton farming scientifically. This might provide suggestions for utilizing agricultural residues and developing the agroecological environment (Li et al. 2020).

4 Impact of Changing Climate on the Quality of Forage Crops

Forage grasses often improve the nutritional value of animals if they have a higher proportion of quickly fermentable substances, such as organic acids, sugar, and proteins, and a lower amount of fiber. Another significant factor affecting fodder quality is the grazing timing and forage harvesting (Lee et al. 2017). In some cases, the effects of changing climatic conditions on fodder quality indicators other than condensed tannin (CT) accumulation have been examined. The initial rate of gas produced during vitro fermentation by rumen microbes was negatively associated with CT concentration when it exceeded 2.5–3.0% of dry matter in *L. corniculatus*. Additionally, it was discovered that *L. corniculatus's* digestibility increased in response to heat and drought but decreased in response to CO2 concentration (Lascano et al. 2021).

In the tropics, changing climate can significantly impact production of livestock, forage quality, availability of water, and cattle food. It is reported that with sufficient soil moisture and nutrients, the tropical C4 forage crop P. maximum cv 'Mombaça' responded effectively to climatic change, preserving leaf dry matter production and PSII performance but decreasing forage quality. However, after exposure to soil water stress and temperature, the quality of forage can be adversely affected, improving the fiber content and lowering the protein concentration, with a considerable decrease in forage digestibility (Habermann et al. 2019).

The Nordic region's fodder production may increase due to warming and an increase in atmospheric CO_2 concentration. Drought is expected to pose a more significant threat to production across many Mediterranean regions. Still, higher CO_2 levels may partially mitigate the effects of drought on growth and photosynthesis (Ergon et al. 2018). Forage crops with their wild species preserve ecosystem services and biodiversity while minimizing the severe impacts of changing climate. Forage crops can adopt severe environments due to their distinctive characteristics, including the deep root system, low production of N_2O and CH_4, higher resource efficiency (water, light, and nutrients), and perenniality, making them appropriate for climate change in the near future (Indu et al. 2022).

5 Impact of Climate Change on the Quality of Horticultural Crops

One of the most essential nutritional components of many horticulture crops is vitamin C. Its concentration is affected by a variety of preharvest and postharvest variables. For example, preharvest light intensity directly correlates with its concentration, while postharvest high temperatures reduce its quantity. Mild drought raises the level of vitamin C (Lee and Kader 2000).

When temperatures are high and there is a water shortage, lettuce leaves become bitter and less tender, and green beans are more susceptible to ozone. The amount of vitamin A and ascorbic acid in tomatoes increases with increased CO2 concentration (Weston and Barth 1997). Higher CO2 during storage time affects mango ethylene production, ethanol production, and color development.

Blueberry flavor is altered and tissue damage is caused by CO2's induction of fermentation. Ozone protects tomatoes against pathogens, delays senescence, and functions as an antibacterial agent (Beckles 2012). Higher CO2 enhances the buildup of acid and sugar in grapevines. Methionine and protein production in peas decrease as temperature rises.

By increasing starch and reducing glycoalkaloids, CO2 elevation enhances potato tuber quality for industrial and domestic use but also lowers protein levels. Additionally, it reduces the tuber's citric acid ratio. Furthermore, it increases tuber malformation, but, because CO2 lessens tuber greening, it has a favorable effect by raising the market value. Protein, methionine, leucine, histidine, potassium, phenylalanine, di-tyrosine, calcium, and aspartic acid have negative relationships with CO2 levels, but glucose, fructose, and carbs have positive stuff. Due to a decrease in physiologically essential amino acids, potato quality is severely reduced.

6 Impact of Changing Climate on the Quality of Sugar Crops

Pakistan's major cash crop, sugarcane, is vital to the country's sugar sector. The content and quality of its sucrose fluctuate with the climate. According to reports, the amount of sucrose decreases in the summer due to heat and humidity, while the percentage of sucrose increases in the winter as a result of cold and dryness. Higher temperature boosts the amount of fiber and hexoses while lowering the proportion of sucrose.

Because of the increased biomass synthesis in sugar beets, sucrose concentration strongly correlates to increased CO2 and lower levels of N-containing plant components. High temperature decreases the amount of sucrose. Due to its osmoregulatory function, glycinebetaine is produced in greater quantities when there is a water deficit (Weigel and Manderscheid 2012; Chołuj et al. 2014).

The development of saccharose is also influenced by drought. The number of cambium rings is not significantly impacted. In times of drought, the attentions of Na, K, amino acids, glycine betaine, fructose, and glucose rise. The concentration of sucrose and compatible solutes are closely inversely correlated (Hoffmann and Kluge-Severin 2011; Loel et al. 2014).

In this section, we discuss the steps that must be taken to meet the increased problems created by climate change while maintaining global food security.

7 Forests

Forests support agricultural systems' resilience in a variety of ways. They help to regulate temperature and water at the landscape level and offer habitat for important species like pollinators. In terms of household livelihood pliability in the face of climate change, forests and trees play significant roles, including:

1. As alternative plans in case of emergency
2. As major producers and sources of income change for residential homes and rural families
3. In the case where agricultural as well as other rural livelihoods are no longer practicable, as sources of employment

8 Livestock and Pastoral Systems

South Asia and sub-Saharan Africa, two areas identified as being mainly vulnerable to climate change, are also places where rural communities and farmers depend most heavily on livestock for income and basic necessities and where livestock is also anticipated to have a greater contribution to food production and improved nutrition. In the previous era, livestock keepers have been able to respond to threats to their means of subsistence, and, in some cases, livestock keeping itself serves as an adaptation plan, particularly in pastoral groups where livestock have traditionally been the primary resource to withstand harsh climatic situations (FAO 2007). In the case of crop failure, livestock can be employed as a technique for variation and risk control (McCarthy et al. 2010).

9 Building Resilience at Landscape Level

Agricultural output is part of a larger landscape that is affected by a variety of biophysical, institutional, and social factors in most areas. Pollination, disease and pest resistance, erosion control, and watershed protection are just a few of the ecosystem services that are important for agricultural production and actually occur at landscape scales. These services have a direct impact on how resilient agricultural livelihoods are by lowering environmental hazards and enhancing strategies to cope (IUCN 2010).

10 Managing Genetic Resources

Future production systems will be dependent on livestock, crops, aquatic organisms, and forest trees that can endure as well as produce in future climates. The objectives of breeding programs will need to be revised in order to achieve this, and in certain cases it might even be necessary to introduce species which have never before been grown in the region. Breeding programs must begin several years in advance since they take time to achieve their objectives. One of the keys to productivity, adaptation, and pliability in production systems is the availability of genetic resources for agriculture and food. They encourage the work that scholars and local communities do to raise the standard and productivity of food security (FAO 2015).

11 Enabling In-Farm and Off-Farm Diversification

Mostly farmers have other sources of income in addition to agriculture, and smaller households frequently have higher percentages of nonagricultural earnings than larger ones. It is also crucial to understand that diversifying away from agronomic sources of income and, in many cases, leaving agronomy in favor of pay opportunities in other sectors are key approaches for boosting resilience among communities depending on agriculture. Admittance to off-farm income sources through labor diversification is typically favorably related with well-being levels in many micro-level researches of agronomic household security.

12 Developing Environmental Monitoring Systems

Climate change will have an important influence on ecosystems, both directly and indirectly, by changing physical and biological properties, such as water quality (acidity, salinity, and temperature) and species distribution. Systems for monitoring the environment should adopt a risk-based methodology in recognition of the fact that increasing hazards require more intensive monitoring. For fisherfolk and farmers to well know the biophysical procedures and contribute to the solution, such as fast variation measures as well as early warning, long-term investment, and social variations, the participation of local actors and the value of locally collected information are extremely vital.

13 Crop Modeling

Common approaches for evaluating the effects on crop productivity due to climate change include mechanistic process-based crop models, which incorporate physical replies of crop development and growth to ecological as well as management variables. Various crop models have been utilized to explore the belongings of climate change on crop yield around the world but with a variety of results (Lobell and Burke 2010). In order to analyze crop responses using cropping systems models (CSM), weather data from general circulation models (GCM), typically crop model, as well as a few GCM forecasts, have been frequently used in the assessment of climate change's effects on agronomy. This strategy has been used in the US Pacific Northwest (PNW), where projections indicate that climate change will primarily have positive effects on the production of wheat, particularly winter varieties.

14 Conclusion

Nature and the environment play a significant role in agriculture. The possible for climate change is considerable for agriculture in this scenario. Agricultural inputs and infrastructure, such as water supplies and soil quality, are being affected. The effects of climate change are severe in many areas. High levels of carbon dioxide and other greenhouse gases cause temperature to rise and precipitation patterns to change. The duration and pattern of cropping will change as a result of this temperature change. Climate change makes diseases and insect attacks more likely. In order to mitigate the effects, we must update our abilities and create adaptive strategies to deal with this situation, which will result in a decrease in agricultural product output and quality and a risk to food security in developing countries for the next century. It is essential that the government and policy makers must be concerned about these climate change challenges. Government must implement policies, show concern, and help farmers adjust to climatic effects.

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Application of Remote Sensing in Agriculture

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Abstract Changing environment and booming population extend the need for a revolution in agriculture for food security as agriculture is the main source of food for humanity. With advancements in information and drone technology, remote sensing makes its way to modern agriculture's recent yield calculation, crop surveys, weed and pest infestation, and their control. All this can be done remotely using the state-of-the-art latest technology available which includes GIS, drones, and optical technologies.

Keywords Agriculture · Remote sensing · Nutrient · Weed · and Pest Management

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_21

1 Introduction

Remote sensing is a science and an art that gathers information, without direct interaction with the object under analysis and provides knowledge about real-world objects. In addition to ground observations, remote sensing is a technology of quantifying natural resources remotely from space to enhance accuracy. Using the electromagnetic spectrum to determine the features of earth is the concept behind remote sensing.

We can use it to track crop growth and development, changing in soil cover, observing of pests and diseases, forecasting about crop yield and harvesting date, accurate farming, and about field observations. Remote sensing (RS) technology is essentially used to detect land resources. Integrated and cost-effective data about earth's study, RS contributes significantly to monitoring the characteristics of the earth (Dubovik et al. 2021). In crop growth and yield prediction, RS inputs, together through crop simulation models, remain very useful. These space-based satellite technologies are becoming increasingly critical in obtaining space-time meteorological and crop status information to supplement conventional approaches, due to the time-consuming and restricted use of ground and air platforms (Kasampalis et al. 2018) (Fig. 1).

In developing countries (like Pakistan), satellite RS is used primarily for agricultural crop yield estimation. Remote sensing technology (RST) will intensely alter the credentials and characterization of agricultural production based on crop and/or soil biophysical possessions (Liaghat and Balasundram 2010). Remote sensing satellites (RSS) would be useful for yield assessment (Doraiswamy et al. 2005; Bernerdes et al. 2012) and Crop Phonological Awareness (Sakamoto et al. 2005; Waqas et al. 2022). Many surveys contain numerous types of RS that are responsible for precise data promptly, and the expense of conventional methods of collecting data is just a small part of traditional methods of collecting data.

2 Crop Nutrients Monitoring

A lot of factors affect the image quality in remote sensing as shown in Table 1, but if the images are pre-processed correctly, multiple vegetation indices (e.g., SAVI, NDVI) consequential from RS data correlate positively with photosynthetic activity, chlorophyll content, and crop yield. The use of a remote sensor mounted on a tractor has now made it possible to apply fertilizers spatially varied in real time. It is common for spray booms on tractors to be fitted with remote sensors. In these systems, nitrogen (N) application rates are determined using vegetation indices (such as NDVI). In real-time, fertilizer is applied by nutrient applicator/spreaders based on this information. Based on observed vegetation indexes, various methods are used to determine the appropriate N-application rate. Typically, the reference vegetation index (VI) is accurately measured in a fertilized (N-rich) experimental unit or strip

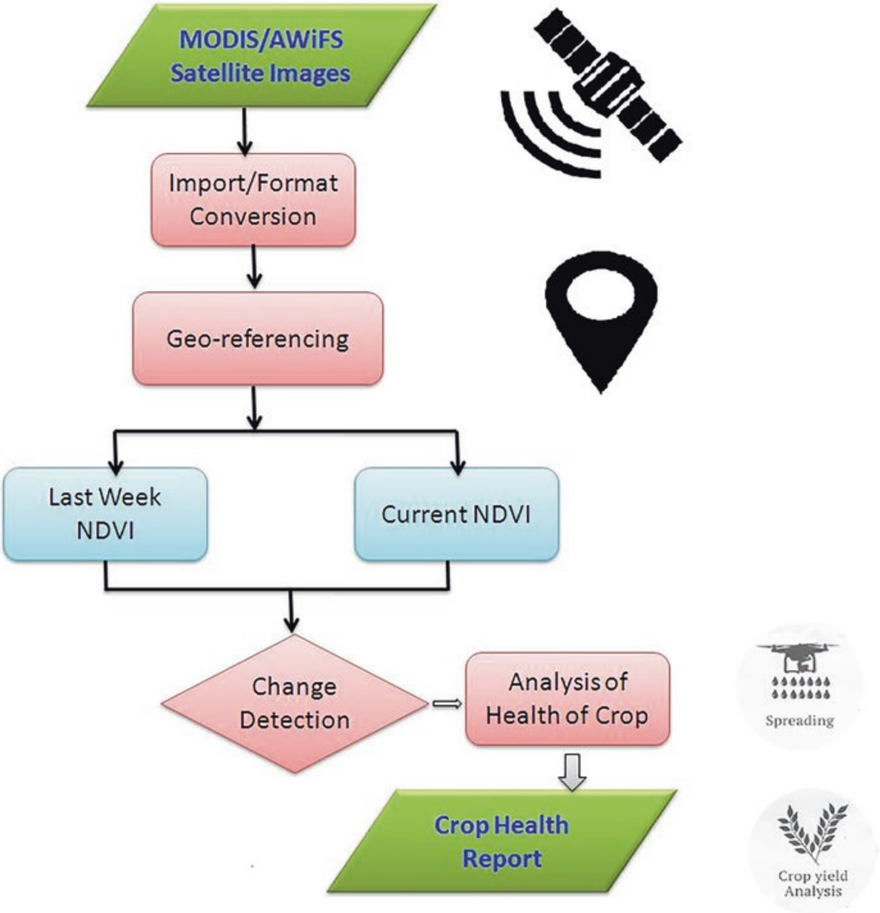

Fig. 1 Technical pathway of remote sensing (RS) in precision agriculture

which is typically of the targeted field, and nitrogen supply rates are computed by linking the measured vegetation indices (VI) in the target plot with the reference vegetation index (VI). Using these commercially accessible sensors that have been designed and successfully implemented, we can calculate the season nitrogen requirements for numerous crops based on vegetation indices (Franzen et al. 2016).

3 Identification of Weeds and Their Management

Weed causes crop yield to decrease as they compete with crops for daylight and other crop supplements (Birch et al. 2011). International capability to produce decreases because of enthusiastic weeds development as it is 43% (Oerke 2006).

Table 1 Factors affecting image quality in remote sensing

Remote sensing systems	Factors
Geometric precision	Sensor position GPS system Viewing angle
Spectral information	Atmospheric absorption Atmospheric scattering Cloud condition Sun position
Radiometric resolution	Number of bits
Spatial resolution	Sensor position Viewing angle
Spectral resolution	Wavelength intervals Bands in electromagnetic spectrums
Temporal resolution	Frequency of image acquisition

The Department of Agriculture, Fisheries, and Forestry (DAF&F) expressed the yield troubles because of weeds are AUD$4 billion for each annum and its expansions in each coming year in Australia (Goktogan et al. 2010). RS techniques will be used to identify weeds and also can be helped in their management.

3.1 Procedures for Detection of Weed Image

There are some kinds of practices to utilize for recognizing crop weeds from symbolism (Penuelas et al. 1993). They incorporate Object-Based Image Analysis (Torres-Sánchez et al. 2015), Maximum Likelihood Classifier (MLC) (Noonan and Chafer 2007), Support Vector Networks (SVN), Spectral Angle Mapper division (SAMD) (Nicolai et al. 2007), Maximum Matching Feature, Self-Organizing Maps (SOM) (Manevski et al. 2011), Neural Network Classifier, and Principal Component Analysis (PCA) (Almeida and Filho 2004; Golzarian and Frick 2011). Collected pictures for brome and rye grass and wheat genotypes at early developmental stages by utilizing PCA have been viable (Golzarian and Frick 2011).

Distinguished weeds in maize by utilizing object-based picture examination (Peña-Barragãn et al. 2012; Pena et al. 2013) and an MCA six camera (Pena et al. 2013). The OBIA method was enacted by line direction count, followed by sharp among uncovered soil and vegetation, characterizing seed items, recognizable proof, and arrangement of the primary harvest and the leftover yield lines. It arrived at 90% of exactness in arrangement for satellite symbolism.

3.2 Application of UAV for Weed Identification

SVM (support vector machine) approach was utilized for picture handling and converting it into vector information design. In a maize crop, same goal was utilized to plan weeds control effectively (Pena et al. 2013; Perez-Ortiz et al. 2015). The primary examination utilizing UAVs for planning grape plantation on the basis of NDVI was utilized in Italy (Primicerio et al. 2012).

By utilizing multispectral symbolism, weeds were related to 99% exact in maize crops (Peña-Barragãn et al. 2012). Moreover, information gathered at the early developing stage was discovered to be entirely appropriate (Torres-Sanchez et al. 2013).

3.3 Weed Discrimination by Multispectral Imagery

Multispectral symbolism has a larger number of groups yet is not exactly hyper spectral which has many groups to browse (Lee et al. 2010). The tetra cam camera can offer the chance to alter the mix of band channels to organize specific applications. They are accessible in 12, 6, and 4 sensor models (multi-criteria approach) and the Agricultural Digital Camera Model (ADCM) (Torres-Sanchez et al. 2013; López-Granados et al. 2016; Saberioon et al. 2013). In sunflower, a six-band camera was utilized to plan weeds effectively with a hundred percent exactness @ 15% weed edge utilizing UAV flown at 30 meters height (López-Granados et al. 2016). The ten nanometer groups (midpoint) were blue, green, red, red-edge, and NIR are 450, 530, 670 to 700, 740, and 780 nm, individually. Different band groups were utilized for gathering symbolism in maize crops for distinguishing weeds, viz., 530 to 570 nm for green, 670 nm for red, and 700 to 800 nm for NIR because they produce a precision of 86% at 30 m height (Peña-Barragãn et al. 2013). These investigations revealed that multispectral symbolism can be utilized to distinguish and recognize weeds in yields, and the vast majority of them utilized MCA six camera from Tetra cam (Peña-Barragãn et al. 2013; Torres-Sanchez et al. 2013, 2014, 2015; Perez-Ortiz et al. 2015).

Weed control is a challenge, and hyper-spectral detecting can give an approach to recognizing contrasts between crop plants and weeds. This technique is utilized to improve traditional strategies for weed recognition (Glenn et al. 2005). Imaging and reflectance spectroscopy strategies may use to recognize different sorts of plants. The ID depends on the varieties in the plant's colors inside the leaf, and the design of the leaf ingests and mirrors light in an alternate manner (Carter 1993). Hyperspectral far-off detecting is generally utilized for various agrarian applications, for example, leaf zone file investigation of agro frameworks (Delegido et al. 2013), planning through soil examination (Gholizadeh et al. 2013), plant stresses (Carter 1993), arrangement of field species (Dale et al. 2013), disease location and distinguishing proof (Calderon et al. 2013), and a partition of harvest species (Wilson et al. 2014).

4 Assessment of Insect Pest Infestation

The diseases and insects that attack on plants can be detected from a distance with the use of remote sensing. According to Riedell and Blackmer (1999), far-off detecting is an innovative and powerful technology to distinguish between health and infected plants. They used far-off detecting methods for the identification of creepy crawly bugs and infection severity on oat plants. They osberved that covering attributes and phantom reflectance contrast between bug invasion and illness. RS procedures also play an important part in evaluating yield determination, land assessments of explicit crops, catastrophic areas, water supply data, and flooding areas.

4.1 Studies on the Existence of Insects Through RS

It is conceivable to recognize the pressure brought about by the BPH in rice utilizing distant detecting. Shading and shading infrared photography with a regular camera have been utilized successfully to outline the damage brought by different insects like hemlock looper and bark insects. Similarly, pressure brought by aphid species can also be distinguished by remote sensing through far-off detection (Yang et al. 2009).

4.2 Application of GIS in Pest Management

Shepherd et al. (1988) digitized recorded results of defoliation brought about by the Douglas-fir tussock moth in British Columbia from 1924 to 1986. This flare-up recurrence map was then overlaid with woods type and bio geo-climatic guides to decide how backwood type and environment were identified with episode recurrence.

4.2.1 Insect Estimation Data and GIS

Liebhold et al. (1996) expressed that the utilization of GIS to interject vagabond moth trap includes and densities of egg mass in an IPM showing program helps in bug evaluation.

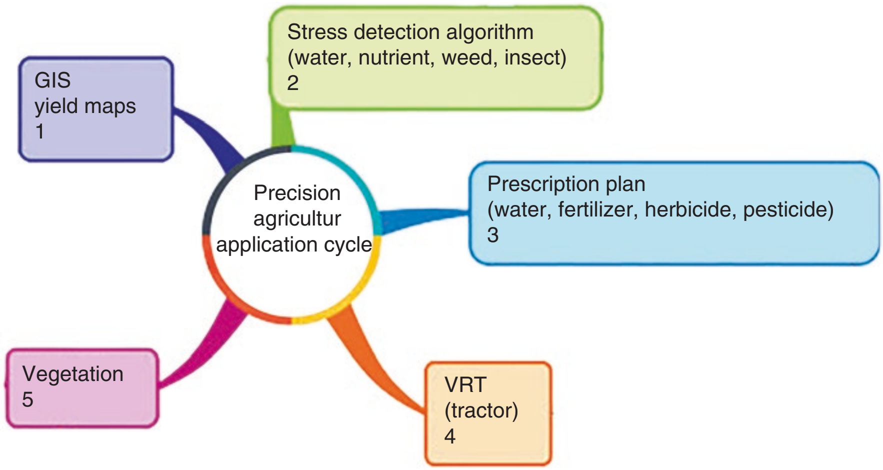

Fig. 2 Implementation of remote sensing in precision agriculture

4.2.2 Locust Observation at FAO

Desert Locust Information Service (DLIS) utilizes precipitation gauges, i.e., primarily infrared and noticeable channels, to see better the spatial and quantitative conveyance of precipitation in the Desert Locust reproducing territories.

Remote sensing is an important technology which has substantial uses in precision agriculture, weed detection, land preparation, incest pest, and disease detection (Fig. 2).

5 Conclusions and Future Prospects

Remote sensing is highly used in measuring several biotic and abiotic stresses in numerous crops, and it is also very helpful in identifying and managing different issues at very low farm levels. For effective utilization of the knowledge on crops for developing the economy, there is urgent need to develop the state level facts based on available studies on many crops derived from RS and GIS methods. The governments can promote the use of RS in order to make important decisions about the policies they will adopt. The nontraditional and new RS application includes the implanting of nanochips in seed and plants tissue that can be used in near-real time to monitor crops. These and other new techniques will reinforce the significance of RS in future analysis of agricultural sciences.

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Mitigation of Climate Change Through Carbon Farming

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Abstract There is still a lot of disagreement concerning the nature, substance, and, most critically, effect of the policy initiatives that are needed to decrease greenhouse gas emissions. Carbon farming is a viable technique for producing food and other products in a more sustainable manner. According to the Food and Agriculture Organization (FAO), livestock emissions account for 24% of world greenhouse gas (GHG) productions, with entire worldwide livestock emissions of 7.1 gigatons of CO2 equivalent per year accounting for 14.5% of overall human-caused GHG emissions. This chapter explains the present condition of climate change mitigation in developing nations using carbon farming and the ways these countries can adopt for increasing carbon sequestration. This chapter also discusses carbon farming, a climate-smart agriculture technique that uses plants to trap and store atmospheric carbon dioxide in soil, along with carbon sequestration. Forestry carbon sequestration, specifically by prevented deforestation, is a potential, cost-effective alternative for mitigating changing climate. We need to improve our biophysical knowledge

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_22

about carbon farming co-benefits, predict the economic impacts of employing multiple strategies and policy incentives, and develop the associated integrated models to estimate the full costs and benefits of agricultural GHG mitigation to farmers and the rest of society. This can be achieved through joining near-real-time field measurements and offline, modeling, computing networks, weather data, and satellite imagery.

Keywords Carbon sequestration · Low carbon agriculture · Agroforestry · Soil carbon monitoring

1 Introduction

In the future decades, the threat of global warming caused by anthropogenic greenhouse gas (GHG) productions will be a huge problem for humans (Kragt et al. 2012). The agriculture industry is a major source of methane (CH_4) and nitrous oxide (N_2O) GHG with higher global warming potential (GWP). N_2O and CH_4 have GWPs of 310 and 21, correspondingly, implying that, over a 100-year time limit, they will trap 310 and 21 times more heat than CO_2. Agriculture emits roughly 6.1 gigatons of CO_2e each year, which account for 10–12% of global GHG emissions (Tang 2016). Conversely speaking, agriculture is also increasingly being shown to have a significant function in removing GHGs from the atmosphere. Farm animals and fertilizer management are important factors to overcome agricultural GHG emissions. Renewable energy resources (such as the utilization of animal manure) can help to reduce GHG emissions both on and off the farm. They might assist agricultural producers to diversify their markets by reducing their dependency on energy sources with fluctuating pricing (Tang et al. 2016).

The easiest, cost-effective, and ecologically friendly method is directly beneath our feet. Carbon may be farmed by storing it in agricultural soils (Miller et al. 2014; Alghabari et al. 2016; Fahad et al. 2016a, b, c, d; Mubeen et al. 2016; Nasim et al. 2016a, b; Rasool et al. 2016). Carbon is usually abundant in soils. They can contain up to 5% carbon by weight in the form of plant, soil organic matter, and animal components in many phases of decomposition. An increasing number of farmers are embracing carbon farming approaches, recognizing agriculture's ability to store enormous amounts of carbon from the atmosphere (Bustamante et al. 2014). Carbon farming benefits individual farmers by improving and sustaining soil, resulting in improved agricultural yields; it also benefits the environment by sequestering carbon and reducing the effects of changing climate (Toensmeier 2016). The purpose of this chapter is to emphasize the significance of C farming in developing countries in terms of minimizing the effects of changing climate (Antle et al. 2010; Khawar et al. 2016; Nosheen et al. 2016).

2 Climate Change in Developing Countries

Many emerging nations have recently experienced more frequent or severe weather events, such as heat waves, floods, tropical cyclones, and droughts than in the past, and the consequential effects point to the importance of future climate changeability and variation on the production systems, livelihoods, and environment. Large portions of Asia, Africa, and Latin America have seen temperature increases in the range of 0.5–1.0 degrees Celsius during the last 30 years; however, certain regions have seen higher changes (Trenberth et al. 2007; Abbas et al. 2017; Fahad et al. 2017; Saud et al. 2017; Zia et al. 2017). Earth surface air temperatures have increased at almost dual the pace of high temperature over the ocean, implying that tiny island states have seen less warming (e.g., in the Pacific). The frequency of warm extremes has increased in lockstep with global warming (Halsnæs and Trærup 2009).

Warming rises the geographic changeability of rainfall, resulting in lower precipitation in the subtropics and more rainfall in advanced latitudes and sections of the tropics (Halsnæs and Trærup 2009). Despite a decrease of monsoonal flows, there is a trend for higher rainfall in monsoonal movements owed to increasing humidity. However, there are still a lot of unknowns when it comes to tropical climatic reactions. Temperature in Africa is expected to be higher than the worldwide yearly mean warming across the island. The tropics will be warmed up more than the drier subtropical areas. In parts of Mediterranean Africa, northern Sahara, and southern Africa, annual precipitation is expected to decrease. Rainfall is predicted to increase in the Sahel, the Guinean Coast, and the southern Sahara (Parry et al. 2007).

3 Stabilizing Greenhouse Gas Emissions

Identifying the so-called stabilization wedges, which are 1 gigaton of CO2 equivalent each year of emissions reductions accomplished by a single method, is a method of presenting possible solutions to the main task of stabilizing and ultimately reducing GHG emissions and fostering green growth. Socolow and Pacala (2004) proposed the concept of stabilization wedges, which entails combining seven different technologies to reduce emissions. Their goal was to provide a realistic, effective, scientifically sound, and politically feasible plan for reducing CO2 emissions. By 2054, each of the identified techniques may inhibit a total of 25 billion tons of emissions.

Applying wedges of the proper level will place the world budget on pace to stabilize GHG releases at levels less than double those of pre-industrial times (Asuka 2012). Despite the uncertainty, this method identifies the expected extent of alteration and the mix of region-specialized policy alternatives available. The benefit of this technique is that policymakers may compare the feasibility of implementing each wedge and determine the number and type of wedges that should be adopted in their respective countries. Low-carbon development difficulties can't be solved by using carbon-efficient technologies in a few specialist markets while leaving the rest unaffected (Ashina and Fujino 2013; Amin et al. 2017a, b; Shakeel et al. 2017; Jabran et al. 2017a, b; Mirza et al. 2017). What's needed is the development and implementation of beneficial technology across a wide range of industries. Main mitigation skills prior to 2030 consist of:

1. Carbon capture and storage
2. Energy efficiency and conservation
3. Forest and soil
4. Renewable energy
5. Fuel switch
6. Nuclear fissions
7. Renewable fuel and electricity

It could be seen from Fig. 1 of stabilization wedges and the list of these key mitigation technologies that carbon capture and storage are at the top if we are to achieve stability in carbon emission.

Many studies have looked into these technologies in order to come up with mitigation solutions. Other studies imply that, using already available technologies, it is possible to halt and possibly reverse the development of emissions in a cost-effective manner. Some Asian countries, such as the People's Republic of India, Indonesia, and China, have previously experienced this.

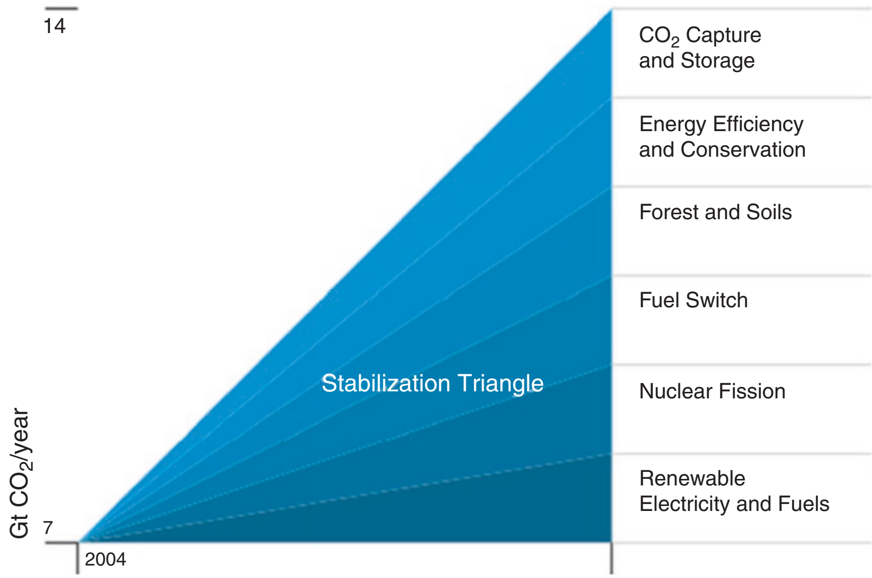

Fig. 1 Emission wedges

4 Ways of Carbon Farming for Developing Countries

4.1 Carbon Farming Through Agroforestry

Agroforestry in the tropics has greater C concentrations than pastures or field crops, according to several studies (Agevi et al. 2016). Around the world, agroforestry is predicted to be adopted on 1000 billion hectares. Agroforestry covers 1 billion hectares, according to Zoomer et al. (2009), 32% in South America, 19% in Sub-Saharan Africa, 13% in Southeast Asia, and the rest in Europe and North America. Each year, agroforestry sequesters between 30 and 322 Pg C (Edenhofer 2014). By 2040, a further 12,000 t C yr-1 might be sequestered if tree management practices are improved, increasing the total to 17,000 Mg C yr-1. In West African Sahel nations, Luedeling and Neufeldt (2012) discovered biomass C reserves ranging from 22.2 to 70.8 Mg C ha-1 (from the arid Sahara Desert to the humid region Guinea). According to Kuyah et al. (2012), the amount of carbon stored in agroforestry systems ranges from 0.29 Mg C ha-1 yr-1 for a fodder bank agroforestry system in the West African Sahel to 15.21 Mg C ha-1 yr-1 above ground and 30–300 Mg C ha-1 up to 1 m deep in the soil. Estimations of above-ground C-sequestration potential (CSP) assume that 45–50% of the dry weight of twigs and 30 percent of the dry weight of foliage contains C. Agroforestry schemes in East and West Africa have a carbon sequestration capability of 6–22 Mg CO2 ha-1 y-1 in soil and biomass (Baccini et al. 2012) (Table 1).

5 Soil Organic Carbon Stocks and Agroforestry

For silvopastoral systems, according to studies in Brazil SOC, stocks to 1 m depth could reach 408 Mg C ha-1. Silvopastoral systems had the greatest SOC stores in the 40 cm layer, followed by coffee and traditional systems and tree crop. Negash et al. (2015) discovered that latitude impacts SOC; this was found after analyzing three aerometry systems in Ethiopia. The greatest SOC stocks (343 Mg C ha-1) were found at high latitudes, while the lowest biomass C reserves (121 Mg C ha-1) were found at low latitudes. The length of time the agroforestry has been practiced,

Table 1 Area of coverage under agroforestry practices

Region	Area under coverage (%)
South America	32
Sub-Saharan Africa	19
Southeast Asia	13
Europe and North America	36

Source: Zoomer et al. (2009)

species contained, soil type, elevation and climate, planting density, pruning, thinning, and the SOC to biomass C fraction in agroforestry practices all influence land use (Nair 2012). Maintaining high SOC levels keeps the system running smoothly, as well as providing indirect livelihood and maintaining a compact population (Negash and Starr 2015; Awais et al. 2017; Hammad et al. 2017; Gillani et al. 2017; Ahmad et al. 2017; Nasim et al. 2017; Mahmood et al. 2017).

Litterfall also promotes to the buildup of carbon stocks in the soil. It's a highly significantly recognized link between soil and vegetation, and it's a good predictor of aboveground efficiency. Litterfall production's contribution to agroforestry systems has received little attention. The impact of any agroforestry system on soil C sequestration is determined by the amount and quality of input provided by tree and non-tree components of the system, as well as properties of the soils themselves, such as soil structure and aggregations.

6 Tree Biomass in Agriculture

In forest ecosystems and pure stand selection, tree biomass estimation has been done. Other land uses, such as agroforestry, however, play an essential part in the mitigation of climate change. Due to the tree architecture and methodological problems involved, estimating tree biomass in agricultural fields is difficult. As a result, a variety of methodologies must be utilized and compared to earlier findings in the same location in order to determine clear tree biomass (Jose and Bardhan 2012). The sequestration potential of different tree species in agroforestry can be determined by the different tree species findings of tree biomass. Biomass output may be increased by exchanging ecological habitats to well-managed agricultural environments. Research reported a 21% increase in SOC pool after 2 years of transformation from a natural to the cultivated habitat (Masera et al. 2003) (Fig. 2).

7 Biochar Role in C Sequestration

CO2 should be captured from the atmosphere over a lengthy period of time, with as little leakage as possible. The usage of biochar for C sequestration is one feasible approach to attain these goals. In a partial supply of oxygen, crops leftovers, trees, leaves, poultry waste and grass clips, and leaves are pyrolyzed into biochar. Biochar has a twofold higher C content than the common resources. Biochar made at low temperatures can be used to boost the amount of carbon in the soil. Biochar has the potential to boost soil carbon sequestration by 1 billion tons of carbon per year or possibly more. Moreover, to agricultural residue preservation in the soil, continuing use of biochar might be fruitful for increasing C sequestration. The retention duration of biochar was predicted to be between 108 and 556 years by Wang et al. (2016), indicating that biochar has a long-lasting retention in the soil. On the other

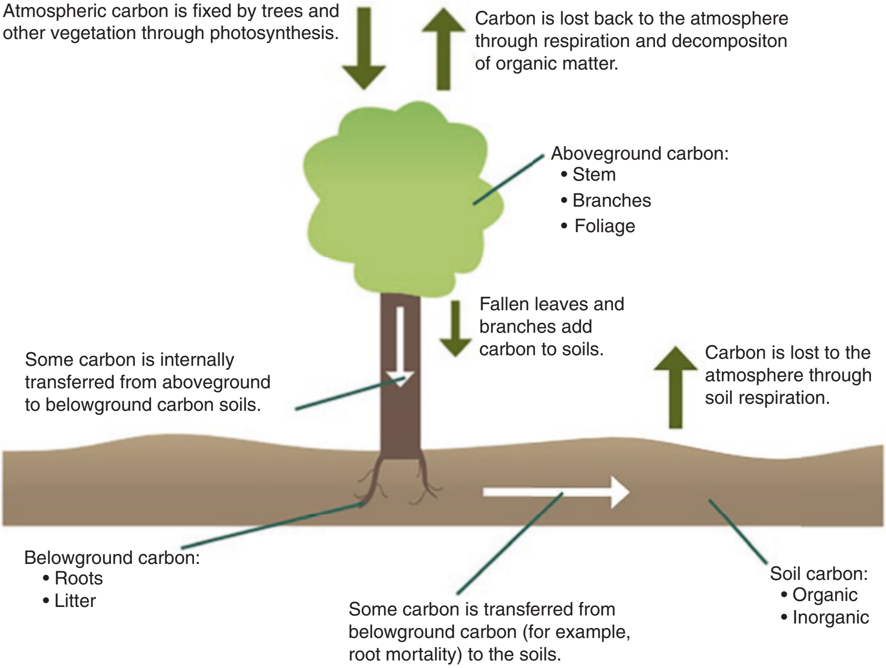

Fig. 2 Pools of carbon in agriculture and forestry

hand, the actual retention time of biochar is a point of contention. It's impossible to predict any significant changes in biochar loss after it's been incorporated into the soil. Biochar, on the other hand, lasts far longer in the soil than fresh plant remnants. As a result, by turning biomass into biochar, certain quantity of carbon might be removed from the carbon cycle. We may be able to have two C cycles as a result of this intervention: (a) biochar to atmosphere C cycle and (b) plant biomass to atmosphere C cycle (Hammond et al. 2011). Thus, more C in the soil may be maintained by making it act as a sink instead of a source of CO2 release by enhancing the environment cycle. As a result, C sequestration can result in a negative C flow (Zhao et al. 2019). The amount of C added to the soil will, however, be determined by the nature of biochar utilized. However, the widespread use of biochar in agronomic patterns may be too expensive (Shahzad et al. 2019).

8 Agricultural Soil Carbon Monitoring

Crop rotations and growing carbon inputs (residue management, soil amendments, cover crops) are examples of carbon farming approaches. Such approaches have the potential to moderately replenish the worldwide soil carbon pool, which has been depleted by land agriculture by 116 Pg of carbon, as well as to recover health and structure of soil and raise crop yields. Annual carbon sequestration rates range from 100 to 1000 kg C ha-1 under various management approaches. Improved observing, verification and reporting of the quantity, and permanence of soil carbon sequestered as a consequence of carbon farming are required to achieve this. The Field Observatory Network (FiON), a network of researchers, companies, stakeholders, and farmers, using carbon farming approaches, may be formed to help achieve this goal. By merging automated near-real-time field observations, satellite imaging, modelling, weather data, and computational systems, FiON has developed integrated technique for monitoring and estimating farming carbon sequestration. Long-term ecological data and monitoring the effects of climate and land use change might be collected by ecological observatory networks such as the National Ecological Observatory Network, the Global Lake Ecological Observatory Network, and other biodiversity observatory networks (Silva et al. 2011).

9 Conclusions

Using less-intensive and more strategically structured farming practices, the agricultural output's reliance on climate change may be maintained. To find farming methods that can regulate the delicate stability among climate change and agricultural yields, the agro-environmental aspects must be extensively addressed. In this setting, carbon farming provides a comprehensive and long-term land-use management solution that benefits both the environment and society. Climate change may be mitigated through lowering GHG emissions and carbon sequestration, which are mostly dependent on climate, soil properties, vegetation, and land-use patterns. We should improve our economic, biophysical, and social understanding of the various consequences of carbon farming practices, as well as build improved and incorporated models, to calculate the complete costs and benefits of agronomic greenhouse gases reduction to growers and the environment. To quantify the overall costs and benefits of agricultural GHG mitigation to farmers and the rest of society, we need to increase our social, economic, and biophysical information about the varied consequences of carbon farming practices, as well as develop better and integrated models. Recommended C agricultural management strategies must be successful and cost-effective, and they must be adapted to specific ecosystems. Carbon farming technology in agriculture might improve efficiency while simultaneously benefiting the environment. However, numerous significant measures have been taken toward guaranteeing appropriate adaptation in emerging nations, more work leftovers to properly recognize the drivers of previous adaptation exertions, the need for future adaptation, and how to integrate climate into overall progress policy. Recommended C agricultural management strategies must be successful and cost-effective, and they must be adapted to specific ecosystems.

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Use of Biochar for Biological Carbon Sequestration

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Abstract Biochar (BC) is produced by pyrolysis process, i.e., when crop residues, biomass, grass, trees, or other plants are combusted at temperatures of 300–600 °C under anaerobic conditions; it enables the carbon in the biomass to resist decay. Biochar is used as an alternative organic source for the improvement of soil fertility, for the mitigation of GHGs associated with agriculture, and for the restoration of degraded land in developing countries. BC can persist into soil for many years because it contains larger proportion of condensed aromatic C, and under specific conditions it can sequester carbon for many hundreds of years. Therefore, improving soil organic carbon (SOC) sequestration is essential for preserving crop productivity and soil health, reducing climate change, and enhancing agricultural

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8_23

sustainability. SOC sequestration can be achieved by increasing carbon inputs and reducing carbon losses. The accumulation of atmospheric carbon (C) in woody products, vegetation, and soils is known as the biological carbon sequestration. All biological substances contain carbon, but plants have the highest carbon storage, such as forests and soils. Carbon is absorbed into the cells of these organisms through photosynthesis and other metabolic processes. Besides bacteria, algae and fungi also play a key role in biological carbon sequestration. BC is significantly used for the enhancement of biological carbon sequestration in agricultural soils. Hence, BC in soils as a C sequestration strategy has received considerable attention over the past few years.

Keywords Biochar · Carbon sequestration · CO_2 impacts · Natural ways of CO_2 sequestration

Abbreviations

BC	Biochar
BCM	Biological Carbon Management
BECCS	Bioenergy Carbon Capture and Storage
CCM	Carbon Concentration Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CMNs	Carbon Management Networks

1 Introduction

Biochar is a kind of charcoal created by a process of pyrolysis; i.e., when crop residues' biomass, grass, trees, or other plants are combusted at temperatures of 300–600 °C under anaerobic conditions, it enables the carbon in the biomass to resist decay. Globally, climate change is mostly caused by anthropogenic carbon dioxide emissions. It has severe impacts on animals, plants, the earth, and humans. Additionally, the burning of fossil fuels results in the release of CO_2 and other greenhouse gases. Carbon emission may pose severe threat to human life and health, wealth, and the stability and existence of nonhuman species and ecosystems. SOC sequestration can be achieved by increasing carbon inputs and reducing carbon losses. Microbial carbon utilization efficiency is determined by the ratio of total soil microbial growth above substrate intake (the total of all microbial respiration, reproduction, and mortality). A key factor in predicting long-term changes in SOC is the microbial carbon consumption efficiency, and higher levels of this factor indicate greater potential for soils to sequestering carbon. Biological carbon sequestration is the most effective method used to mitigate carbon with the help of plants like algae, fungi, yeast, bacteria, and clostridium that can sequester carbon in them. Biochar and mixture of biochar compost is used as an alternative organic source for the improvement of soil fertility, for mitigation of GHGs associated with agriculture, and for the restoration of degraded land in developing countries (Abbas et al. 2017; Agegnehu et al. 2017; Amin et al. 2017a, b; Fahad et al. 2017; Saud et al. 2017; Shakeel et al. 2017; Jabran et al. 2017a; Zia et al. 2017). Most research that have been published were performed on soils of developed nations that are less degraded as compared to developing countries (Zhang et al. 2016). In many developing countries, open dumping method for solid municipal waste is commonly used that causes landfill leachate discharge and pollution through gaseous emission. A carbonaceous material generated from any biomass is called biochar, so municipal solid waste can be converted into biochar which can be utilized for the mitigation of contamination and resource recovery. For the reduction of odor, biochar works as a cover material (Alghabari et al. 2016; Fahad et al. 2016a, b, c, d; Mubeen et al. 2016; Khawar et al. 2016; Nosheen et al. 2016; Rasool et al. 2016; Gunarathne et al. 2019). The largest economic benefit of adding biochar to the unproductive and poor soils present in those areas is frequently observed in the developing rural regions of low-income countries. Labor and other expenditures are greater in middle-income countries; therefore, alternative technical agricultural advancements can increase crop production. Between North-Western Europe and Sub-Saharan Africa, the economic output of BC production and applications in cereal crops significantly varies. This was primarily because of variations in the agricultural benefits of BC amendment and pyrolysis cost used to make the biochar. There are currently no studies that comprehensively analyze the economic and environmental impacts of using biochar in agriculture in each middle-income and developing nations (Ahmad et al. 2017; Amin et al. 2017a, b; Shakeel et al. 2017; Jabran et al. 2017a, b; Mirza et al. 2017; Hammad et al. 2017; Gillani et al. 2017; Owsianiak et al. 2021).

2 Causes of CO_2 Emission

Both natural and manmade methods are used to release CO_2 into the atmosphere.

2.1 Natural Emission

Carbon cycle (soil, ocean, air) emissions, volcanic ash emissions, forest cover loss owing to forest fires, and other natural calamities like cyclones, hurricanes, volcanic eruptions, and tectonic plate movements are all examples of natural CO_2 emissions.

2.2 Artificial Emission

Power plants, vehicles, wood burning, deforestation, incineration, plastic waste burning, paper industry, textiles industries, metal factories, urbanization, plastic production, and waste disposal are among the artificial sources of carbon dioxide emission resulting from human activity. Among these, the fossil fuel burning was the primary source of high CO_2 emissions. In addition to natural CO_2 emissions, CO_2 emissions rose by almost 60% from 1940 to 2005. The electricity-generating industry was the leading source of CO_2 emissions, accounting for almost 146 percent of global emissions. The automobile sector emits around 121 percent of CO_2, followed by 66 percent from industries, 45 percent from urbanization, 41 percent from forests, and 27 percent from building construction, which indirectly releases about 76 percent of carbon dioxide into atmosphere. Because of the population growth, 61 percent of carbon is emitted to fulfill their everyday needs, which functions as an indirect source of elevated CO_2 in the air. The use of fossil fuels alone is expected to account for 111% of carbon dioxide emissions in 2030. The gas usage in the energy sector emits 22% CO_2, whereas the use of coal emits 44% and 22% from automobiles, respectively (Nasim et al. 2016a, b, c, 2017; Awais et al. 2017; Mahmood et al. 2017; Dong et al. 2019).

3 Impacts of CO_2

3.1 On Earth

The fundamental component for climate changes throughout time is increased CO_2 emissions in the environment, so the natural balance has been disrupted.

3.2 On Plants

Plants respond to higher carbon dioxide in positive and harmful ways. The rate of photosynthesis in plants can increase with enough nutrition and water availability. Increased CO_2 has the following negative impacts on plants: altered transpiration rate, lower nitrogen and phosphate content in their leaves, decreased stomatal conductance, reduced leaf area, and reduced leaf size. Plant reproduction is reliant on certain varieties display decreased blooming length and many flowers, and some plant species generate thick capsules in fruit. Some plant species generate thick capsules in fruit, which prevent pollinating insects from entering; while some plant species produce thick capsules in fruit, which hinder pollinating insects from entering. Some plants had beneficial benefits like a rise in the number of blooms and seeds. The disadvantages, on the other hand, exceed the advantages.

3.3 On Animals

As CO_2 levels rise, creating a high rate of plant regeneration, new plant and animal species may evolve because of biological succession. Animals' molecular levels alter as a result of elevated CO_2. CO_2 has a direct impact on the metabolic processes of animals. Respiration becomes tough, and renal damage caused by electrolyte imbalances has all been described. The lungs, kidneys, and bones are the main targets, and the parathyroid glands' function is affected (Gayathri et al. 2020).

3.4 On Humans

A human body's typical CO_2 tolerance is about 0.5 percent, or 5000 ppm, lasting less than 8.5 hours. Hypercapnia is a medical disorder; it happens when a high quantity of CO_2 is inhaled, resulting in acidosis and elevated acidity in the blood. The decrease in pH of tissue causes aberrant respiratory activity and circulation of blood to the heart that causes harm to the central nervous system, as well as neurological injury and other things (shock, headaches, hyperventilation, vision loss, and damage to the central nervous system). High CO_2 exposure can cause dizziness, headaches, giddiness, tachycardia, trouble breathing, and other symptoms. Short-term exposures to carbon dioxide between 1 and 5% affect lung functions, as well as decreased breath duration, alveolar damage, and increased renal calcification; symptoms include unpredictable behavior, panic attacks, abnormal mitosis, and changed enzyme metabolism. Around 40,000 parts per million of carbon dioxide for about 12 hours is fatal, CO_2 intoxication occurs at 50,000 parts per million, and catalepsy/unconsciousness occurs at 70,000 parts per million. Acute toxic effects of CO2 are severe, and dosage of around 9% or 90,000 parts per million for lower than 6 minutes, with neonatal mortality occurring at less than 80,000 parts per million and psychological alterations such as emotional irritation, has been recorded and reported (Gayathri et al. 2020).

4 Biochar

Biochar is rich in carbon substance made from organic raw materials and generated by restricted oxygen thermal combustion. Many organic wastes, agriculture waste, and municipal solid waste, for example, can be utilized as biochar feedstock. Sludge is a type of solid waste, generated during wastewater treatment. However, because it is high in carbon and nutrients like ammonia, it is a suitable feedstock for biochar synthesis (Zhang et al. 2020). Biochar offers its own set of benefits, including a strong cation exchange capability, high carbon content, wide structural stability, and surface area (Younis et al. 2016). As demonstrated by the increase in the number of published publications regarding biochar in the last 10 years, it has gotten a lot of attention. Biochar removes heavy metals and organic contaminants mostly by adsorption (Gai et al. 2014). BC is a porous aromatic carbon-rich substance made by carbonizing biomass at high temperatures in oxygen-limited environments. Biochar has been useful in a variety of fields, including energy, the environment, and agriculture. Biochar has sparked interest in areas such as metal ion immobilization, photocatalytic destruction of organic pollutant, wastewater treatment, soil improvement, and carbon sequestration during the last several years (Hu et al. 2020). Biochar has been shown in studies to efficiently remove inorganic and organic pollutants from water by sorption (Guo et al. 2019). Furthermore, biochar made from a variety of feedstocks has been proven to reduce nitrogen leaching and increase NH_4^+ sorption in agricultural soils, decreasing nutrient loss (Hale et al. 2013). Furthermore, nitrogen-rich biochar might be used as a fertilizer in the soil (Sanchez-Monedero et al. 2018).

Trash materials may be used to provide low-cost feedstocks for biochar synthesis while also lowering waste disposal expenses. It also has the environmental benefit of reusing and reducing trash. Pine sawdust is one example of a waste material that may be used as a low-cost feedstock for biochar manufacturing. Wheat straw is a readily accessible agricultural by-product that may be used as a biochar feedstock (Kumar and Bhattacharya 2021).

Biochar, in comparison to activated carbon, has a good capacity to remove hazardous metals from aqueous media. The inclusion of amino, carboxyl, and hydroxyl groups, which may bind metal ions, may account for biochar's improved efficiency. As a result, biochar is an effective sorbent for removing a wide variety of cations and anions. Animal conversion of dung to biochar is a practical and cost-effective approach for reducing hazards to the environment such as carbon dioxide emissions and contaminant leaching from manure. It's also crucial to figure out how biochar interacts with pollutant such that longer binding or release of pollutant from BC material may be determined (Batool et al. 2019).

5 Biological Carbon Sequestration

Direct capture and sequestration of carbon is a process that involves removing carbon dioxide from exhaust emissions and preserving it for a long time to reduce emissions. Biological CO_2 mitigation (BCM) is the conversion of CO_2 into organic carbon by autotrophic organisms and plants through photosynthesis, resulting in huge volumes of biomass (Kheirfam 2020). Carbon can be found in all biological mediums, but plants have the biggest carbon storage, for example, forestry and soils (like peat), and a substantial amount is naturally sequestered in the ocean throughout time. Carbon is absorbed into the cells of these organisms through photosynthesis and other metabolic processes (Liu et al. 2020). Biomass might be utilized for several economic applications with careful control of the carbon cycle while also ensuring that enough carbon is stored in a biological medium, allowing CO_2 levels in the atmosphere to remain safe (Zhang et al. 2021). Biomass might be utilized for a variety of purposes, including biofuel, food, feed, and biochemical synthesis. CO_2 is recycled in biofuel production (Olah et al. 2018). The earliest carbon fixation process that occurred millions of years ago give rise to today's fossil fuels. Photosynthesis is a mechanism in which some organisms consume anthropogenic carbon to generate biomass. Making use of this technology, CO_2 concentrations in flue gases collected can be used in a controlled setting to produce vast volumes of biological media; this will result in a big volume of usable biomass for biofuel production as well as many by-products with additional value. Concerns about global warming and C emissions generated interest in fossil fuel-based C sequestration options (Llorach-Massana et al. 2017). The burning of fossil fuels for energy generation accounts for a substantial portion of anthropogenic carbon dioxide (CO_2) emissions. Emission of CO_2 is predicted to grow greatly in the coming years as energy needs rise, especially in emerging nations (Kessel 2000). Because of increased development rates, soil and vegetation carbon will rise with minor increases in atmospheric CO_2. However, at greater levels of atmospheric CO_2, growth is hindered because photosynthesis reaches its maximum level, whereas soil respiration rate increases as the temperature rises, elevating atmospheric CO_2 levels even further (Cao et al. 2017). The ocean absorbs more than a quarter of all human-caused CO_2 emissions. As a result, it acts as the world's principal natural carbon sink. When CO_2 levels in saltwater get too high, carbonic acid is generated; ocean acidification is the name given to this phenomenon. Since the beginning of the industrial revolution, there has been a 30 percent rise in ocean acidity (Ma et al. 2020). The capacity of marine creatures to form shells and maintain skeletal integrity gets affected when water acidity levels rise. At depths of 1000 meters or more, non-swimming marine creatures like zooplankton, benthos, and bacteria would be the most affected by ocean acidification. Rising ocean acidity is expected to increase the extinction of marine life in the future, while the long-term impacts remain unknown (Chu et al. 2020). Strict CO_2 management, including post-combustion carbon sequestration, will be necessary to fulfill energy demands while minimizing CO_2 emissions.

6 Biochar Use for Carbon Capture and Storage

BECCS (bioenergy carbon capture and storage) is a system, before capturing and storing CO_2 emissions in geologic materials, which creates energy from biomass. While the gaseous emissions are collected and utilized, ash and solid residue, that accounts for about 1% of wood mass, is routinely landfilled, resulting in nutrient loss to the environment (Maraseni 2010). Although wood ash is not a technically difficult product to handle, there is still a great opportunity for improvement in terms of resource management and handling (Smith 2016). Biochar is a result of biomass pyrolysis, which includes high temperatures and depletion of oxygen. By increasing the C ratio and cross-linking C atoms in biomass during thermochemical conversion, a very stable, aromatic C lattice is formed (Sheng and Zhu 2018). Because of its chemical and microbiological stability, biochar has been proposed for carbon sequestration in the soil to combat climate change. BECCS and biochar can only be adopted on a wide scale if there is a carbon price. Since both technologies are expected to compete for biomass resources and BECCS has a higher carbon sequestration potential, BECCS may appear to be a no-brainer when compared to charcoal. Biochar, on the other hand, is believed to be less harmful to the environment in comparison to other harmful carbon technologies like BECCS, as well as reduced cost and energy needs (Lal et al. 2018). Several factors impact the product's distribution and properties, including the maximum treatment temperature (HTT) and the kind of feedstock employed. Biochar's carbon sequestration capability is boosted by increasing retention time of carbon in solids and stable C content within it. BC formation is known to be stimulated by alkaline and alkali earth metals found in ash biomass (Crombie and Mašek 2015).

6.1 Methods for Reducing CO_2 Emissions into the Atmosphere

To reduce CO_2 emissions in the atmosphere, a combination of methods is necessary, which includes the steps that follow:

- The quantity of CO_2 emitted entering the ambiance needs to be decreased.
- High levels of CO_2 already existing in the air are removed/eliminated.
- CO_2 from the atmosphere is used to make commercial goods (Tashiro et al. 2018).

7 CO_2 Sequestration

CO_2 from the atmosphere is reused and recycled, a novel approach that has been widely adopted. Carbon dioxide is sequestered using both natural and anthropogenic ways. CO_2 should be gathered from the atmosphere. For doing this, carbon is gathered and a raw substance that is used in the creation of carbon-based products of several kinds. Storage and capture of CO_2 is an excellent method for removing CO_2 from the air.

8 CO_2 Collection Via Artificial Means

Harvesting atmospheric carbon dioxide, isolating it from other gases, transferring, and sealing it for storage and CCS process, includes determining appropriate carbon dioxide sources of pollution and implementing appropriate CO_2 separation technologies from other gases and impure chemicals (Yu et al. 2012). The energy industry, the power generation sector (thermal energy), certain manufacturing, and transportation industries are the principal sources of CO_2 emissions into the atmosphere and are cause of pollution of land, water, and air. Direct or indirect CO_2 capture from emission sources can be done by using various materials to filter the flue gas, such as absorbent, adsorbent, membrane, or metal catalyst. To extract CO_2 from other sources, such as cars and atmospheric air capture, CCS facilities are being built near high-emitting sources or close to those locations. CO_2 capture from sources with a CO_2 level of around 20% has become crucial, requiring the use of filter materials for CO_2 filteration and prevent it from releasing into gaseous form (Koytsoumpa et al. 2018).

9 CO_2 Capture Via Natural Means

Through a sequence of metabolic processes within photosynthetic organisms, biomass is produced from atmospheric CO_2. Biomass currently provides 12 percent of the world's energy. By replenishing the soil with fresh planting, plants serve as an unending natural resource for getting energy. In comparison to other renewable energy sources, biomass has the benefit of encapsulating energy in organic bonds. Wood, agricultural wastes, biofuel, and natural gas are all examples of biomass. Biomass is a different approach for storing CO_2 that has been collected. Various species, plants, bacteria, fungi, yeast, and algae are only a few of the organisms that have been discovered which are engaged in turning CO_2 into biomass. To recover wasteland, plants that convert more energy potencies, have quick growth rates, and have low fertilizer and pesticide usage must be cultivated. A vast amount of resources are needed to create plant biomass and energy. Algal farming in small ponds, tanks, lakes, and the sea, for example, has broadened and opened up a key avenue for producing bioenergy. Algae are high-yielding mini-factories that can produce energy and biomass at a fast rate (Anwar et al. 2018).

10 CO_2 Sequestration

Microorganisms and plants, such as bacteria, algae, fungus, and yeast, use two methods to sequester carbon: one is photosynthesis, and the other is non-photosynthetic processes. CO_2 is incorporated into cellulose, lignocellulose, chitin, hemicellulose, lignin, and other organic carbon products by both autotrophic and heterotrophic organisms. The correct use of these organisms for CCU can result in environmentally benign CO_2 sequestration. Different routes, conversion processes, and the potential to create biomass/bioenergy are present in these species.

11 Plants

Photosynthesis integrates CO_2 from the atmosphere into the body of the plant. Chlorophyll is a factory that utilize suns radiant energy to transform CO_2 into a biomolecule, which is the foundation for dark and light activities. Microbial systems that trap carbon dioxide in the atmosphere into biomass and energy include photosynthetic and nonphotosynthetic processes. The following are some of the advantages of CO_2 collected by microbes: Great maximum rate of biofixation production, with greater capacity to bioremediate ambient carbon dioxide and extraordinary ability to create a variety of additions. There are no issues with genetic augmentations, they can be utilized in bioprocessing in companies, they develop quickly and continuously in bioreactors, there is no rivalry, and there is no food scarcity. Bacteria, fungus, yeast, and algae, for example, are all included (Razzak et al. 2013).

12 Bacteria

Bacteria are unicellular bacteria that come in 19 different types. These six categories include the autotrophic Cyanobacteria, Eubacteria, and Archaebacteria that fix CO_2 for organic C synthesis (Senatore et al. 2020).

13 Clostridium

Organic carbon molecule decomposition, acid generation, and the cycle of CO_2 were all aided by anaerobic gram-negative bacteria. The hydrogen molecules provide the energy necessary to fix carbon dioxide. Both acetyl CoA synthetase and carbon monoxide dehydrogenase convert carbon monoxide to carbon dioxide and are required for acetyl-CoA synthesis. This bacterial sp. is unable to live in the presence of oxygen in the atmosphere, which is a significant disadvantage. The first model utilized to explore this pathway was *Clostridium thermoaceticum* (Albuquerque et al. 2016).

14 Proteobacterium

Proteobacteria are phyla that can capture CO_2 from the atmosphere through a variety of biological mechanisms, Some bacterial species are utilized to make commercial goods like biopolymers and pharmaceuticals. Polyhydroxy alkanes are generated in the *Ralstonia eutropha* cytoplasm by using CO_2. *Desulfobacter* *hydrogenophilus* reduces sulfur by converting CO_2 and H_2O into organic molecules, with the ATP-citrate lyase separating oxaloacetate and acetyl-CoA.

15 Algae

For converting carbon dioxide into biomass or energy, algae are the most efficient photosynthetic biofactories. They are available in a variety of sizes, ranging from macro to tiny. Macroalgae generate a lot of lipids; therefore, they're utilized to make biodiesel. In the Calvin–Benson cycle, RuBisCO uses CO_2 enzymatically. For example, a kilogram of microalgae removes 1.84 kg of CO_2 from the atmosphere. *Chlorella vulgaris* fixes 6.24 g/L/d of carbon dioxide, whereas *Anabaena* fixes 1.46 g/L/d. They make biomass and bioenergy out of CO_2. Cultivating these algae near CO_2 emitters can help to reduce CO_2 levels while also providing a lot of biomass and biodiesel. To get the highest output, considerations such as algae species selection, appropriate growth parameters, and adequate feedstock should be made prior to growing procedures. To obtain maximal CO_2 biofixation and yield, the ideal algal species should have the following characteristics. The capacity to collect carbon and the rate at which it is incorporated should be exceptional. It should be able to withstand high CO_2 levels, adequate nutrition consumption, and temperature and H+, OH parameter fluctuations. This suggests that the amount of CO_2 exposed to the algae have a significant influence on the rate and yield of bioconversion. This clearly shows that *Chlorella* sp. has a remarkable endurance to high CO_2 concentrations. They have a high tolerance for CO_2 concentration, up to 40–41 percent at 30 °C and pH 5–6. It has been observed that a high carbon dioxide concentration may, in a short amount of time, dramatically enhance the rate of photosynthetic CO_2 biofixation and that more than 5% (v/v) is hazardous. In addition, continuously injecting a high quantity of CO_2 into the culture medium limits algal development. Biocarbonate and CO_2 is transferred between cell membrane and chloroplasts functional units in Cyanobacteria. Bicarbonate molecules are transported into the cytoplasm by certain carrier molecules despite the periplasmic limitation of dissolved inorganic carbon. Bicarbonates are then transferred by carboxysomes, in which the carbonic anhydrase CA enzymes was activated in the cytosol, as a result of this action. This method promotes photorespiration by increasing rubisco carboxylation activity over the oxygenation process. This process includes transferring and using CO_2 and bicarbonates, while also separating and concentrating RuBisCO in specific microchambers and controlling the CA activity. In order to recycle and restore the environment, algal biorefineries must be built on wastewater sources. Macroalgae, often known as seaweed, produce biomass and energy by using CO_2 from the environment. They are used as a feedstock for fermentation-based biofuels like bioethanol, methanol, and isobutanol because they produce a lot of carbohydrates and have a low lipid content (Moreira and Pires 2016).

16 Fungi

Multicellular eukaryotic species have a thick cell wall, and fungi are multicellular eukaryotic organisms. They are heterotrophic and play a crucial role in the terrestrial ecosystem as decomposers and in collecting carbon. Saprophytic and mycorrhizal fungi are classified based on how they degrade organic compounds. Compound-degrading enzymes are produced by a saprophytic fungus. Mycorrhizal fungi can only digest a small portion of these compounds due to a shortage of enzymes, that are required for the carbon cycle and mineralization. Plants and mycorrhizal fungi have three types of symbiotic interactions: arbuscular mycorrhizal, ericoid mycorrhizal, and ectomycorrhizal which is present in *Ericales* plants. The mycelium serves as a carbon storage site. As a result of the effective incorporation of CO_2 at a greater percentage, a huge amount of biomass is created. Mycelia, fungus-generated vegetative tissues, have a fast growth rate and extand swiftly in soil which allow the accessibility of nutrients and water. Biomass generation, secondary products, and necromass breakdown are all ways that fungi contribute to CO_2 sequestration. The kind of fungus species present in the soil, as well as the biomass created by them, determines the rate of carbon sequestration—the more mycelia produced, the more carbon is absorbed. Even the soil's aggregates include a fully developed fungal necromass that helps in storing carbon (Clemmensen et al. 2013).

17 Yeast

Yeast is a unicellular microbe that is frequently utilized in large-scale businesses for fermentation to produce a variety of commercial goods. The yeast strain *Saccharomyces cerevisiae* is frequently employed in the fermentation process. Carbon dioxide is released as exhaust gas during fermentation as a result of microbial respiration, and a considerable amount of oxygen is consumed. In yeast, the processes of glyoxylate and the Krebs cycle were observed. Carbon from glycerol is transformed into glycerol-3-phosphate by cytoplasmic kinase before reaching the mitochondria. The FAD-dependent glycerol-3-phosphate dehydrogenase enzyme converts it to dihydroacetone phosphate in mitochondria, which then enters the glycolytic pathway (Ghayur et al. 2019).

18 Prospects of Use of Biochar for Carbon Sequestration

A key limitation in such systems is the lack of biomass at geographically suitable range to land sinks. Aside from such supply-side concerns, there are also risks linked with the transmission of other biochar-borne contaminants to the receiving soil that must be considered. These pollutants have the potential to harm the environment and human health, and they can nullify BC benefits of C sequestration. The quantity of carbon that may be added to soil also has a realistic maximum limit. Future large-scale BC-based CMNs will likely necessitate the use of computer models to maximize benefits while minimizing risks. It includes: (i) the restoration of degraded soils through conversion to agricultural land use; (ii) the adoption of suggested management methods such as no-till farming, manure, and compost-based organic farming; and (iii) BC usage as a soil amendment. According to current estimations, biochar can remove 1–1.8 Pg CO_2–C equivalent per year from the atmosphere. Biochar is a stable carbon compound generated by pyrolysis and gasification as a by-product. Biochar comes in two forms: powder and pellets. In fire-affected soils, char can account for up to 35 percent of total organic carbon (TOC). Biochar was discovered to dramatically improve soil fertility through increasing soil organic carbon (SOC) and nutrients. Biochar's ability to restore damaged lands (such as salty soils and mine tailings) has recently been confirmed. Crop residues left on agricultural fields, on the other hand, can be utilized to promote cover crops as a SOC storage/sequestration method; conservation tillage advantages include nutrient cycling, water runoff management, wind erosion control, and crop production. Kenney et al. (2015) discovered that removing residues (such as *Zea mays* L. or maize stover) reduced soil C while increasing crop production. The fact that this research produced such disparate results reflects the very varied character of soils. Because crop residues are sources of organic C in SOC pools, their removal can significantly reduce SOC levels (Tan 2019).

19 Soil Quality and Carbon Status as a Result of Fresh Crop Residues

Early integration of crop residues (e.g., 63 days before transplanting) sequesters a higher proportion of C than late incorporation (14 days before transplanting) The additional organic C inputs from crop residues impact SOC sequestration. A meta-analysis of changes in C dynamics owing to straw C inputs, for example, found a strong positive association ($R2 = 0.80$) between the overall amount of straw carbon input and the amount of SOC sequestered. The modified soils' greater crop production results in an extra organic C input (Jandl et al. 2014).

20 Effects of Residue Assimilation on Soil Active C Fraction

Crop leftovers can help enhance the active percentage of carbon in the soil. Abbasi et al. (2015) have demonstrated that the inclusion of plant residues significantly affect the C mineralization-immobilization turnover rate of soils. Increased turnover rates may increase the risk of C mineralization, as well as the emission of CH_4 and CO_2. As a result, crop residue integration may improve C sequestration in some instances (Majumder et al. 2019).

Carbon, in the form of CO_2, is a vital component of the C cycle, and a crucial photosynthesis source atmospheric CO_2 levels have risen dramatically in the previous 150 years, from 250 to 418 parts per million, concequently widespread fossil fuels uses. Because of the greenhouse gas effect, this accelerated CO_2 release is a major source of climatic change, which led to ecological imbalance, global warming, biogeochemical cycles changes, ocean acidification, species extinction, altered rainfall, melting ice caps, impacts on soil fertility, eutrophication of lakes, and metabolic changes, at the molecular level. CCS and CCU are two ways of gathering CO_2 from the environment, storing it, and using it, and permanently storing it in geological places. CO_2 is collected and utilized to generate polymers, biofuels, and reactants, among other value-added products. CO_2 is naturally filtered by plants and microbes.

Although C sequestration in agricultural systems has the potential to be a win-win approach, gaining equitable involvement from farming communities that have traditionally relied on cookstoves and other low-tech thermochemical conversion equipment is a big issue. Agricultural residue vs. biochar made from crop residues in soils and the consequences for SC sequestration. Crop residues improve the rate of mineralization of SC, but biochar can increase or reduce SC depending on the kind of biochar/soil and the amount of time it is exposed to it. As a result, while turning agricultural wastes into biochar may be more successful at sequestering SC, it may or may not be more cost-effective (Bai et al. 2019) (Table 1).

21 Conclusions and Research Suggestions for the Future

With a few exceptions, where greater C losses were detected (e.g., elevated CH_4 emission following the addition of wheat residue), both biochar and crop residues resulted in SC gains. While biochar had two different impacts on SC mineralization depending on the source material and pyrolysis temperature, agricultural residues increased SOC. Several studies found that biochar made from wheat straw residue was more efficient than rice straw biochar in sequestering carbon. Many bits of evidence from fragmented lab studies utilizing non-commercial biochar in a very short field experiment or under lab settings or in soils high in SOC, on the other hand, might raise doubts about biochar's potential function in agriculture (Xie et al. 2016). Overall, biochar appears to have a higher positive influence on total soil SC, whereas agricultural wastes appear to boost soil microbial biomass C. In other situations, however, crop residue removal has been observed to reduce soil C levels. The following management factors should be addressed to obtain

Table 1 Biochar made from different agricultural residues being used for carbon sequesteration

Residue type	Crops	Duration type	Soil C status	
Wheat straw	Maize	5 months	4.9–6.3 g/kg increase in SOC	Zhang et al. (2011)
Wheat straw	Rice paddy	2 years	12.6–12.8 g/kg increase in SOC	Zhang et al. (2012)
Wheat straw	Rice	5 months	12.8–13.4 g/kg increase in SOC	Zhang et al. (2010)
Green waste	Radish	6 weeks	43 g/kg increase in C content	Chan et al. (2008)
Lump charcoal	Radish	>79 days	C sequestered ~64% of control	Rogovska et al. (2011)
Oak wood	Artificially degraded soil	4 months	0.5% increase in soil carbon	Mukherjee et al. (2014)
Rubber tea	Rice	54 days	0.52% increase in SOC	Shanthi et al. (2013)
Wood chip	Maize, grass	3 years	0.26–0.51% increase in total carbon	Jones et al. (2012)
Organic waste substrate	Maize, wheat	5 years	29.0–38.1% SOC derived from maize residue 611.973.8% SOC derived from wheat residue	Dong et al. (2018)

greater SC sequestration using soil additions made from raw crop residue or biochar: pyrolytic circumstances, tillage method, and crop residue type (C:N) (temp, duration, etc.). To better understand the relative advantages of agricultural residues and biochar generated from the same sources and then applied to the same soil at the same time to the same crop as independent experiments, comparative studies of their impact are needed. Until this happens, it's impossible to say whether or not the sequestration of SC will be greater when raw agricultural wastes are turned into biochar for soil treatment. This feature also removes a key hurdle, potentially allowing BC based on CMNs to become an applicable NET alternative. Biological carbon sequestration is an essential factor to consider for improving climate change conditions. CO_2 has numerous benefits over other carbon sequestration microalgal fixation technologies since the biomass may be used to create electricity, which is regarded desirable owing to economic gains. BC can be landfilled for the improvement of carbon sequestration capacity and lower its CO_2-abatement costs. Biochar ash composites may boost plant development in addition to sequestering carbon in the subsurface by repairing damaged or deficient soils and offering direct nutrient delivery via biochar. More comprehensive case studies are needed to examine the economic feasibility of SC sequestration using agricultural wastes with and without thermolysis because soil deterioration is a major concern in poor countries and is often connected to poverty (Majumder et al. 2019).

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W. N. Jatoi et al. (eds.), *Climate Change Impacts on Agriculture*,
https://doi.org/10.1007/978-3-031-26692-8

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