Shah Fahad · Mirza Hasanuzzaman
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Muhammad Adnan *Editors*

Environment, Climate, Plant and Vegetation Growth

Springer

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ISBN 978-3-030-49731-6 ISBN 978-3-030-49732-3 (eBook)
https://doi.org/10.1007/978-3-030-49732-3

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

Contents

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About the Editors

Shah Fahad completed his Ph.D. in 2015 in the field of Agronomy and Crop Physiology (Climate Change) from Huazhong Agriculture University, Wuhan, China. Later, he completed his postdoctoral research in the field of Crop Physiology and Climate Change from Huazhong Agriculture University, Wuhan, China. Presently he is serving in the Department of Agronomy, The University of Haripur, Pakistan. His research work encompasses plant stress physiology and antioxidant metabolism, coping with weather adversity and adaptation to climatic variability. Dr. Shah Fahad has published over 220 articles in peer-reviewed journals having an impact factor of 610.34. He has edited 10 books and handwritten 35 book chapters on important aspects of plant physiology, plant stress tolerance, and crop production. According to Google Scholar Citation, Dr. Shah Fahad's publications have received about 5847 citations with an h-index of 40 and i10- index of 128. He is an editor and reviewer for more than 10 peer-reviewed international journals and was a recipient of the Publons Peer Review Award 2019. He has been honored by different authorities for his outstanding performance in different fields like research and education and received the Young Rice Scientist Award in 2014 and Distinguish Ph.D. Scholar of Huazhong Agricultural University in 2015. Dr. Shah Fahad has won 9 international and 3 national projects.

Imtiaz Ali Khan is Professor in the Department of Entomology at the University of Agricultural University, Peshawar, Pakistan. Currently he is working as Vice Chancellor of Swabi University, Khyber Pakhtunkhwa, Pakistan. He received his Ph.D. in 2003 from the University of Bonn, Germany. Dr. Imtiaz Ali Khan has been involved in research with IPM of insects and mite pests of fruits, vegetables, and field crops since 2003. He has completed several national and international research projects. Dr. Imtiaz Ali Khan has published 110 articles and chapters related to IPM, plant physiology, and environmental stresses with Springer, Elsevier, Wiley, etc. He has supervised 30 M.S. students and 9 Ph.D. students as the main supervisor. He is involved in editorial activities and is a reviewer for a number of international journals.

Mukhtar Alam is Dean of the Faculty of Sciences and Pro-Vice Chancellor of The University of Swabi, Khyber Pakhtunkhwa born in 1965. He earned his Ph.D. in the year 1995 from the University of Wales, Aberystwyth, UK, on the Ministry of Education, Pakistan, Merit Scholarship. He served for more than 10 years in Civil Services of Pakistan. He has been associated with teaching, research, and administration in the field of biological sciences. He is the member of national and international organizations. Prof. Alam wrote multiple books on agriculture and is the author of more than 100 articles. As a key speaker, he attended international conferences, congresses, symposia, and workshops. Prof. Alam organized international level conferences in his home country. He secured funding of million dollars from national and international organizations. Throughout his professional career, he held the following positions: Vice Chancellor, Dean, Chairman, Coordinator, Director R&D, Additional Registrar, Deputy Director of Oil Board, and Section Officer.

Mirza Hasanuzzaman is Professor of Agronomy at Sher-e-Bangla Agricultural University in Dhaka, Bangladesh. He received his Ph.D. in “Plant Stress Physiology and Antioxidant Metabolism” from the United Graduate School of Agricultural Sciences, Ehime University, Japan, as a recipient of a scholarship from the Japanese government (MONBUKAGAKUSHO). Later, he completed his postdoctoral research at the Center of Molecular Biosciences, University of the Ryukyus, Okinawa, Japan, as a recipient of the Japan Society for the Promotion of Science (JSPS) postdoctoral fellowship. Subsequently, he received the Australian Government’s Endeavour Research Fellowship for postdoctoral research as an Adjunct Senior Researcher at the Tasmanian Institute of Agriculture, University of Tasmania, Australia. Mirza Hasanuzzaman has supervised 20 M.S. students. His current work is focused on the physiological and molecular mechanisms of environmental stress tolerance. Prof. Hasanuzzaman has published over 120 research publications in peer-reviewed journals. He has edited 12 books and written 45 book chapters on important aspects of plant physiology, plant stress responses, and environmental problems in relation to agricultural plants. According to Scopus®, Prof. Hasanuzzaman’s publications have received roughly 4400 citations with an h-index of 33. He is an editor and reviewer for more than 50 peer-reviewed international journals and was a recipient of the “Publons Peer Review Award 2017, 2018, and 2019.” He has been honored by different authorities for his outstanding performance in different fields like research and education, and has received the World Academy of Science Young Scientist Award (2014). He has attended and presented 25 papers at international conferences in many different countries (USA, UK, Germany, Australia, Japan, Austria, Sweden, Russia, Indonesia, etc.). Prof. Hasanuzzaman is an active member of 40 professional societies and is currently the Acting Research and Publication Secretary of the Bangladesh JSPS Alumni Association. He is also a fellow of The Linnean Society of London.

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Muhammad Adnan is Lecturer in the Department of Agriculture at The University of Swabi (UOS), Pakistan. He has completed his Ph.D. (soil fertility and microbiology) from the Department of Soil and Environmental Sciences (SES), the University of Agriculture, Peshawar, Pakistan, and Department of Soil, Plant and Microbial Sciences, Michigan State University, USA. He has received his M.Sc. and B.Sc. (Hons) in Soil and Environmental Sciences from the Department of SES at the University of Agriculture, Peshawar, Pakistan. Dr. Adnan's main research interests are soil microbiology and plant nutrition, including fertilizer use efficiency, N losses, management of legume N_2 fixation for increasing cereal production, and management of organic wastes for sustainable agriculture production. He has published over 84 peer-reviewed articles, 3 book chapters, edited 1 book, and has received over 2.4 million PKR in research funding as a Co -PI. He has presented his research work in 7 international and 6 national conferences. He has also organized two national and three international conferences in Pakistan. He is the member of the Canadian Society of Soil Sciences, Soil Science Society of Pakistan, and Weed Science Society of Pakistan and was a member (2014–16) of BOS in the Department of Geology at UOS and currently a BOS member in the Department of Environmental Sciences at UOS.Dr. Adnan is the recipient of three Gold medals [one in B.Sc. and two in M.Sc. (Hons)], President of Pakistan Award [B.Sc. Hons)], Indigenous Ph.D. scholarship, and IRSIP grant for Michigan State University, USA, in his educational career. He was also awarded Best University Researcher Award for the year 2015 by UOS.

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Abbreviations

Cd	Cadmium
EGTA	Ethylene glycol tetraacetic acid
CDTA	Cyclohexanediaminetetraacetic acid
OC	Organic carbon
ABA	Abscisic acid
AQPs	Aquaporins
SAR	Systemic acquired resistance
ISR	Induced systemic resistance
P	Phosphorus
Pi	Inorganic phosphate
AR5	Assessment Report
CO_2	Carbon dioxide
IPPC	Intergovernmental Panel on Climate Change
GHG	Greenhouse gases
N	Nitrogen
CEC	Cation-exchange capacity
SOM	Soil organic matter
FAO	Food and Agriculture Organization
USSL	United States Salinity Laboratory
FC	Field capacity
Ca	Calcium
Mg	Magnesium
PO_4^{3-}	Phosphate ions
Al	Aluminum
Fe	Iron
Mo	Molybdenum
K	Potassium
S	Sulphur
PGPR	Plant growth-promoting rhizobacteria
ACC	Aminocyclopropane-1-carboxylic acid
ECe	Electrical conductivity of the saturated soil extracts

ST	Salt tolerance
APX	Ascorbate peroxidase
DHAR	Dehydroascorbate reductase
MDHAR	Monodehydroascorbate reductase
AsA	Ascorbate
ROS	Reactive oxygen species
MAS	Marker assisted selection
N_2O	Nitrous oxide
CH_4	Methane
PFCs	Perfliorocarbons
HFCs	Hydrofluorocarbons
SF6	Sulfur hexafluoride
SOC	Soil organic carbon
N_2O	Nitrous oxide
DCFC	Direct carbon fuel cells
MFC	Microbial fuel cell
Cu	Copper
US-EPA	United States Environmental Protection Agency
WWF	World Wildlife Fund
UNNC	United News Centre report
UNISDR AF	United Nations Office for Disaster Risk Reduction – Regional Office for Africa
UNEP	United Nation Environmental Programme
UN	United Nations
SOD	Superoxide dismutase
POX	Peroxidase
MNR	Ministry of Natural Resources
Pb	Lead
IBSRAM	International Board for Soil Research and Management;
GR	Glutathione reductase
GSH	Glutathione
GLASOD	The Global Assessment of Soil Degradation;
VLP	Virus-like particles
NSIDC	National Snow and Ice Data Centre
GCC	Global climate change
ITS	Internal Transcribed Spacer
KP	Khyber Pakhtunkhwa
NCBI	National Center for Biotechnology Information
BGI	Beijing Genomics Institute
MEGA	Molecular evolutionary genetic analysis
BNF	Biological nitrogen fixation
PGPR	Common plant growth promoting rhizobacteria
NSF	National Science Foundation
ENSA	Engineering Nitrogen Symbiosis for Africa
BBSRC	Biotechnology and Biological Sciences Research Council

NUE	Nitrogen use efficiency
ICAR	Indian Council of Agriculture Research
FACE	Free Air Carbon dioxide Enrichment
AM	Arbuscular mycorrhizas
KSA	Kingdom of Saudi Arabia
ECiw	Electrical conductivity
SAR	Sodium Adsorption Ratio
SARadj.	Adj. Sodium Adsorption Ratio
SSP	Exchangeable Sodium Percentage
RSC	Residual Sodium Carbonate
CSLF	Carbon Sequestration and Leadership Forum
CCS	C capture and storage
CDM	Clean Development Mechanism
GIS	Geographic information system
PS	Salinity Potential
TMA	Tripartite moving average
IHRA	Identical halves rainfall average
TDI	Total dissolved ions
NDVI	Normalized difference vegetation index
SSP	Soluble Sodium Percentage
VG	Vector generation
CSLF	Carbon Sequestration and Leadership Forum

Chapter 1
Carbon Cycle in Response to Global Warming

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Abstract Global warming is a crucial problem in the whole world since the nineteenth century. There are several reasons responsible for global warming. Most considerable from them are anthropogenic activities. Through a variety of human activities, greenhouse gases are continuously released into the atmosphere which resulted in raised Earth temperature. Various greenhouse gases are emitted into the atmosphere. Most common of them are CO_2, methane, nitrous oxide, SO_2, and ozone. CO_2 emission usually occurred naturally by plants in dark, through human respiration and the natural carbon cycle. But, due to anthropogenic activities, the significant amounts of CO_2 are released into the atmosphere which is above the normal threshold limit. High concentrations of CO_2 caused Global Warming. Global warming, in turn, disrupts natural carbon cycle which releases more CO_2 into the environment. Thus, this cycle is continuously running with disastrous effect on the natural earth's environment. Natural carbon cycle normally occurred by the degradation of SOC (soil organic carbon) by a variety of microbes and other chemical reactions which then released CO_2 in the atmosphere. But, due to the decline of organic carbon in the soil, a huge amount of CO_2 is being released into the environment. This process has disastrous effects on not only humans but also on plants and

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_1

other wildlife. This chapter reveals the effects of global warming on the natural carbon cycle which is the prime concern of today's studies.

Keywords Climate change · Greenhouse emission gases · Methane, nitrous oxide · Temperature

1.1 Introduction

Carbon is one of the most important elements of the periodic table. In nature, the major Carbon reservoirs are atmosphere, ocean, plant, soil and fossil fuels. Carbon keeps flowing among these reservoirs. If Carbon concentration is disturbed in one reservoir it automatically affects the carbon concentration of other reservoirs. Higher carbon concentration in the atmosphere results in an increase in the global temperature. However, Carbon is not the enemy as it is very essential for life on earth. It is necessary for soil health. Photosynthesis is driven by CO_2. The micro-organisms play an important part in converting the carbon compounds into stable, life-giving organic compounds (McDonough 2016). The processes of decomposition and fossil fuel combustion releases the CO_2 into the atmosphere again. The increased CO_2 concentration in the atmosphere has increased as a result of deforestation, industrialization, transportation and current human lifestyle which resulted in a global climate shift (Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib ur et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar-ur et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b).

In 2013, IPPC (Intergovernmental Panel on Climate Change) reported an increase in the global mean surface temperature of 0.8 °C from 1880 to 2012 with an increase of about 0.72 °C from 1951 to 2012. Global warming is a major problem which is leading to climate change in most of the countries throughout the world. The crucial factors responsible for global warming include disastrous human activities. Changes in the environment now exceeded the limits of natural divergence. Human activities lead to the release of greenhouse gases in the environment through a variety of sources which ultimately increase the environment's temperature, commonly known as global warming (Wheeler and Watts 2018). Species are now forced to pass through more rigorous selection pressures and will require more adaptation to persist in the environment which will ultimately affect the evolution of the organisms (Monroe et al. 2018a). It has been estimated that at the end of the current century there will an increase of 3 °C in temperature if the current trends continue. Efforts are now being made to somehow limit the global warming around 1.5 °C above pre-industrialization but serious efforts are required to do so (Monroe 2018b). Scientists have now accumulated experimental evidence to prove human involvement in global climate change like ozone depletion, pollution, etc. (Santer et al. 2018). The ozone layer has an important role in maintaining the normal temperature of the ecosystem. The continuous release of greenhouse gases above certain limits depleted the ozone layer which ultimately leads to the global warming (Santer et al. 2018). This chapter aims to provide insights about natural Carbon cycle and its response to global warming.

1.2 The Carbon Cycle

The biogeochemical cycle through which carbon is exchanged among carbon reservoirs like biosphere, pedosphere, hydrosphere, and atmosphere of the Earth is called the Carbon Cycle (Fig. 1.1). In nature, carbon is the main component of the biological compounds as well as the minerals e.g. limestone. The carbon is among the important cycles on the earth which make it sustainable for life. It provides a description of the carbon recycling, re-usage, sequestration and release from the sinks.

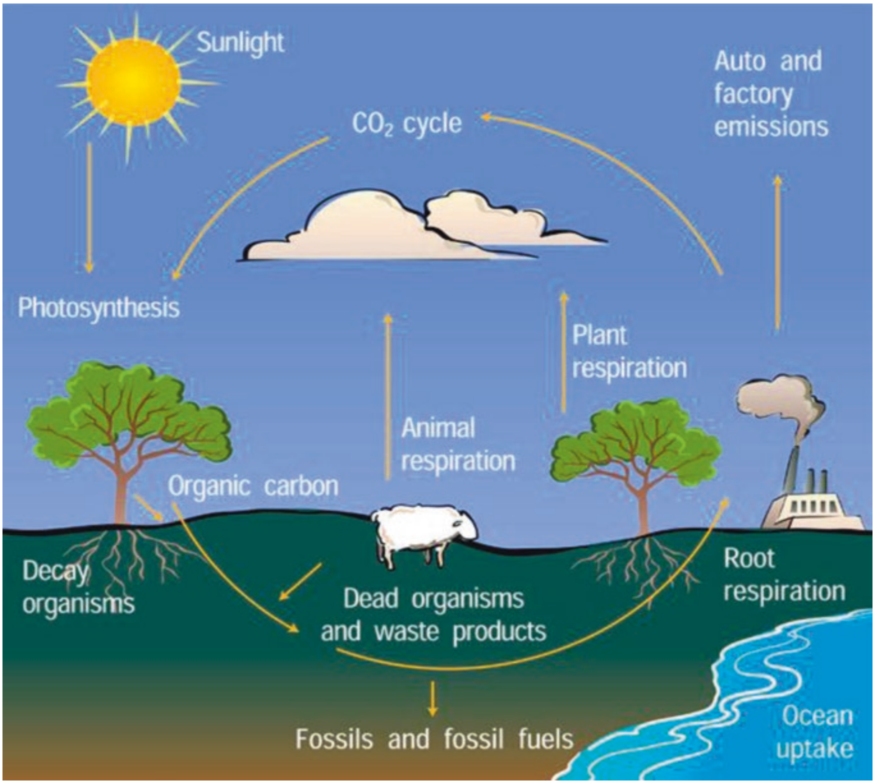

Fig. 1.1 Global Carbon Cycle

Overall, there are five carbon pools: the aquatic pool is the huge one among pedologic, geologic, atmospheric and biotic pools (Fig. 1.2). All these pools are connected with each other and carbon flow between them.

Carbon dioxide concentration was low in atmosphere before industrial development. One study revealed that CO_2 concentration was approximately 280 ppm before industrial development. After industrial development, in 2008 concentration raised up to 384 ppm (Tans et al. 1990). Human activities and isolation of CO_2 from sea water and land have 50% contribution in increased level of CO_2 (Menon et al. 2007; Raupach et al. 2007). Inland waters have major role in CO_2 emissions. Inland water includes natural ponds, rivers, streams, wetlands and reservoirs. No doubt they cover only 1% of earth but they have significant contribution in CO_2 emissions as compared to terrestrial and marine ecosystem (Richey et al. 2002; Cole et al. 2007; Tranvik et al. 2009; Battin et al. 2008; Harris et al. 2012). 0.6 pg carbon buried inside water inlands per year (Richey et al. 2002). It is equal to 20% of carbon which is thought to be buried inside soil and terrestrial ecosystem. Carbon buried inside sediments over thousands of years (Richey et al. 2002; Einsele et al. 2001). Some stable carbon buried inside sediments may reach lithosphere. Due to deficiency of oxygen in inland water as compared to oceans inhibits decomposition of sedimentary carbon and further its emission into atmosphere. This whole process is well presented in (Fig. 1.3). Organic carbon mobility from terrestrial ecosystems to inland water resources is an attention grabbing situation which is responsible for climate change (Battin et al. 2009). To understand carbon seclusion primary step is to find out where this process occurs. After this it is necessary to understand processes that maintain and enhance it. For instance, when soil erosion occur it create a path by which carbon move from land to inland water resources. However, reservoirs, sea water maintain their sediments and bounded carbon (Richey et al. 2002; Battin et al. 2008). They also block carbon movement from water to other inland

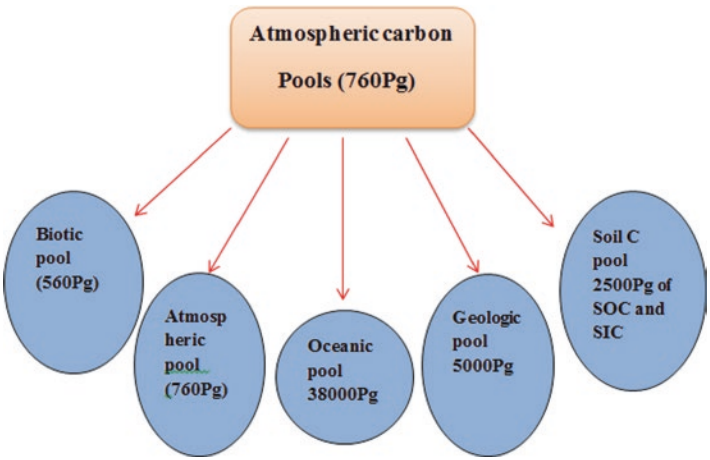

Fig. 1.2 Five worldwide carbon pools. Biotic, Atmospheric, Aquatic, Geologic and Pedologic

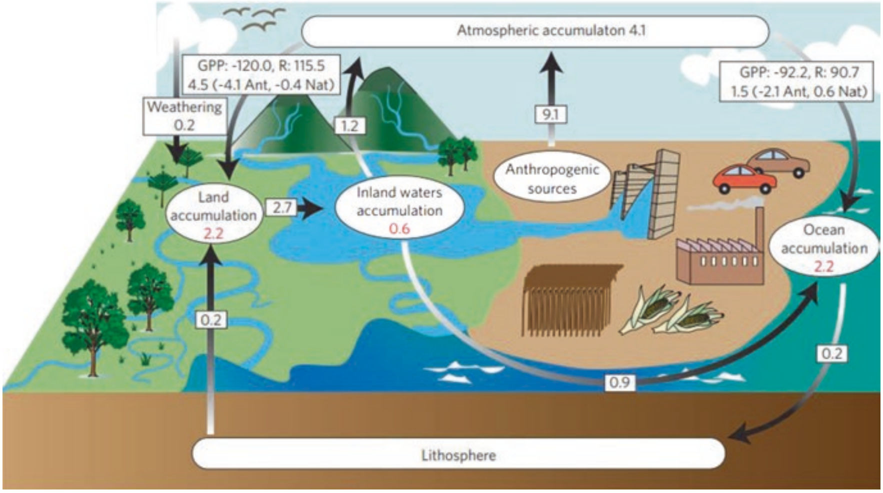

Fig. 1.3 "Abundant carbon cycle" (Battin et al. 2009). The symbolic diagram represents net carbon flow from inland water resources (Richey et al. 2002), and from anthropogenic activities (Raupach et al. 2007). It also includes carbon influx before the industrial development (Menon et al. 2007). Black values represent carbon influx among carbon pools and rate of change in carbon flow represented by red values. This figure also reveals total carbon flow from atmosphere to land and water resources, anthropogenic activities responsible for carbon production and total usage of carbon by organisms depend on photosynthetic process. Ecosystem respiration (R) and Gross primary production (GPP) are poorly constrained (Luyssaert et al. 2008; Del Giorgio and Duarte 2002). CO_2 produced by human activities intake by sea water also include in this net carbon flow (Menon et al. 2007). Influx of carbon from lithosphere represents discharge of CO_2 into firm basins and flow of carbon from lithosphere to land show abrasion of elevated sedimentary rocks also represented in diagram (Menon et al. 2007)

water resources. Furthermore, it is unclear till yet that either sediment's burial resulted in net increase of carbon seclusion or sea water and land responsible for it (Harden et al. 2008). Land use alterations can worsen the effects of inlands outgassing on climate. Inland's water carbon when mineralized then released as CO_2 in atmosphere. But, other lakes, ponds, rivers also release methane (CH_4) into atmosphere. CH_4 is also greenhouse gas and absorb more heat than equal amount of CO_2. Hence, it also has major role in higher temperature of atmosphere. Reservoirs created for hydrolytic power plants and agriculture also released methane into atmosphere (Richey et al. 2002). So, inland water resources responsible for carbon seclusion, its release into atmosphere and resulting warm environment.

1.3 Global Warming

From the mid of the nineteenth century, human activities have disturbed the biogeochemical cycles like the global carbon cycle with an unnatural increase in the Carbon Emission and other greenhouse gases like methane, nitrous oxide, etc. which resulted in increased average global temperature. The temperature rise resulted in soil degradation, agricultural land productivity loss, desertification, biodiversity loss, ecosystem degradation, freshwater resource reduction, ocean acidification and depletion of stratospheric ozone. Global warming will ultimately affect agricultural resources through reduced water availability, alteration, and shrinking of arable land, increased pollution, and toxic substance accumulation in the food chain (Srivastav 2019). The atmospheric Carbon Dioxide (CO_2) concentration increased from 277 parts per million (ppm) to 405 ± 0.1 ppm in 2017 which indicates a continuous rise in the atmospheric CO_2 concentration since the beginning of the industrial era (Alshboul and Lorke 2015). Before industrialization, the atmospheric CO_2 increase was mainly because of deforestation and other land use activities (Alshboul and Lorke 2015). However, after industrialization, fuel combustion became the primary source of anthropogenic emissions to the atmosphere. Since 1750, human beings are responsible for the release of 555 pentagrams of Carbon in the atmosphere which increased the atmospheric CO_2 concentration to a record level in 800.000 years (Battin et al. 2009). The human activities which are somehow involved and can disturb the natural phenomenon are referred to as anthropogenic activities (Barnes et al. 2019). With an increased level of CO_2, temperature rises which give rise to sea level as a result of thermal expansion which results in temporary changes that usually very rapid. The reason behind this is the change in ocean circulation (Flückiger et al. 2006). Environmental warming is responsible for the decrease in rainfall (Allen and Ingram 2002) which ultimately affect water supply for living organisms. Significant decrease in rainfall occurred in some areas including southern Africa, parts of southwestern North America and Mediterranean (Burke et al. 2006). Due to the melting of glaciers and ice pools water drained into the sea and its level raised up. Antarctica and green lands ice pools/ice sheets also melted due to the warm atmosphere and have observed in many areas. One recent study proved ice sheets raised sea level up to 1–2 m. However, one other study suggested that air rather than warm atmosphere responsible for rapid glaciers melting. CO_2 emission has already imparted irrevocable effects on the planet. Further carbon dioxide discharged into the atmosphere through various anthropogenic activities would contribute to more irreversible catastrophic effects on the environment.

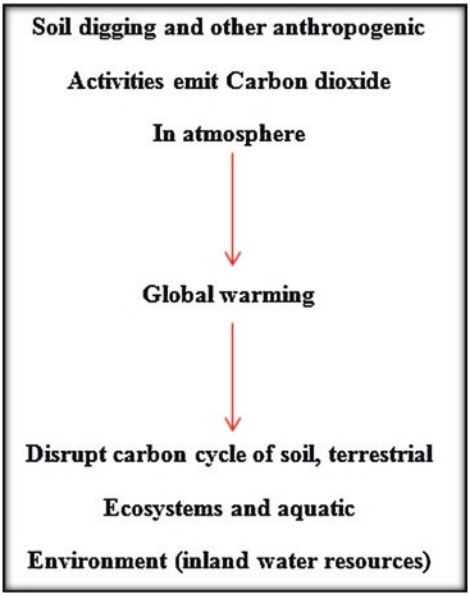

Fig. 1.4 This fig shows the flow of carbon in the atmosphere. Various anthropogenic activities e.g. digging, deforestation, biomass burning, and soil erosion emit CO_2 in the atmosphere which results in global warming. Global warming, in turn, disrupts natural carbon cycle/carbon pool resulting in enhanced CO_2 emission in the atmosphere. In this way, CO_2 concentration get increase day by day in an atmosphere

1.4 Effects of Global Warming on the Carbon Cycle

As discussed above, that increase in CO_2 in atmosphere accelerates global warming (increase in earth's temperature) which in turn disturbs carbon cycle. Terrestrial ecosystems and inland water resources produce more CO_2 under warming as illustrated in (Fig. 1.4). Here we discuss the effects of global warming on the biogeochemical carbon cycle.

1.5 Global Warming and Soil Properties

1.5.1 Soil Respiration

The CO_2 released from microbial activity along with the CO_2 released from plant respiration is known as Soil Respiration. This flux is the second largest carbon flux on Earth (Smith 2002). Despite the fact that the dynamics of this flux are not clearly understood (Watson et al. 2000), the scientists have reached the conclusion that climate change especially the Global warming is affecting the soil respiration flux and its rate. As compared to the atmosphere, the Earth's soil store about twice the Carbon. Over time the carbon concentration releasing from the soil to the atmosphere is increasing (Prentice et al. 2001) but the degree to which Global warming is affecting the carbon flux from soil to atmosphere is the current topic of investigation for many Scientists (Rossati 2017). Observations indicate that soil surface heterotrophic to soil respiration has been increased from 0.54 to 0.63 between 1990 and 2014. It was also noted that both heterotrophic respiration and soil respiration to gross primary production has increased over time. From a study, it was concluded that global heterotrophic respiration is rising in response to climate change (Peters et al. 2017). This suggests that climate-driven losses of soil carbon are currently occurring across many ecosystems, with a detectable and sustained trend emerging at the global scale.

1.5.2 Soil Carbon Feedback

Carbon Cycle feedback to global warming is a poorly understood concept (Change 2013). Experiments suggest that carbon feedback will play an important role either in accelerating or slowing down climate change (Stocker et al. 2013) but the magnitude and of this feedback cannot be predicted. The potential switch of the terrestrial biosphere from carbon sink to Carbon source depends on temperature sensitivity trend of soil organic matter decay (Buttigieg et al. 2016) and complex carbon-nitrogen interactions for the understanding of which as long term field-based experiments are required (Peters et al. 2017).

1.5.3 Soil Organic Matter

Wetlands, permafrost, and peatlands have a high stock of organic carbon as compared to mineral soil on the earth surface (Moftakhari et al. 2017). They make the largest carbon stock globally. Permafrost and peatlands are mostly present at parallel surfaces where the temperature is mostly higher (Hassol 2004) Soil's organic matter stock resulted from a balance between input and output resources below the ground as shown in (Fig. 1.5). Inputs come from roots and leaf debris. Output sources resulted from CO_2 outflow from the soil. Methane outflow and leaching of other organic matter are also significant. Microbial decomposition of organic matter and soil respiration are responsible for the presence of carbon in the soil. These processes rely on temperature and also require water. Carbon dioxide is the main product of organic carbon's breakdown in the soil. Similarly, dissolved organic carbon, dissolved inorganic carbon, aquatic particulate organic components, and methane are also significant transports in soil. Recent extreme weather conditions like heatwaves, droughts, storms, etc. which are caused due to global warming can be a reason for carbon sinks destruction and cause a net loss of carbon from Carbon Stocks releasing CO_2 to the atmosphere (Madakumbura et al. 2019). Extreme weather events can trigger immediate or time-lagged ecosystem responses like mortality, fires or insect infestation (Dai 2011). This indicates that a small shift in the weather conditions can reduce carbon concentration in the sinks and may give positive feedback to climate changing.

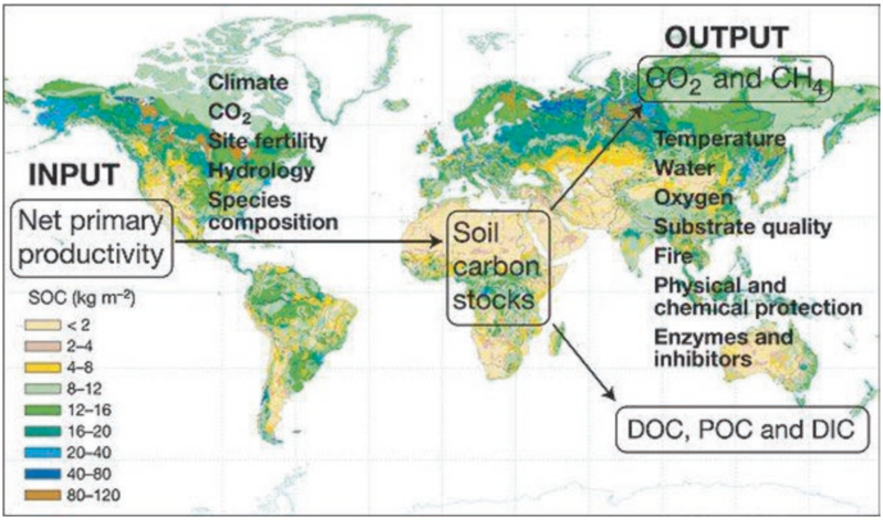

Fig. 1.5 Factors affecting input and product of soil's carbon, highly obtrude over worldwide carbon map

1.5.4 Microbial Decomposition

The soil microbial species responsible for the decomposition of organic soil material are the cause of 50–70 Pg Carbon emission into the atmosphere annually that is approximately 7.5–9 times of the Carbon emissions caused by human activities. The decomposition process is sensitive to the constant climate change due to global warming as it affects the global carbon cycle. Many scientists are interested in researching the impacts of global warming factors on the microbial decomposition activity the interspecific interactions also have a great impact but they give rare importance (Raich and Potter 1995). The combination of global change factors alleviated the bottom-up limitations on fungal growth, stimulating enzyme production and decomposition rates in the absence of soil animals. However, increased fungal biomass also stimulated consumption rates by soil invertebrates, restoring microbial process rates to levels observed under ambient conditions. Our results support the contemporary theory that top-down control in soil food webs is apparent only in the absence of bottom-up limitation. As such, when global change factors alleviate the bottom-up limitations on microbial activity, top-down control becomes an increasingly important regulatory force with the capacity to dampen the strength of the positive carbon cycle-climate feedbacks (Crowther et al. 2015).

1.6 Future Perspectives

The carbon cycle is responsible for the circulation of CO_2 in the atmosphere. Anthropogenic activities are greatly responsible for the disturbance of the Global Carbon Cycle. In-depth study of biogeochemical Carbon Cycle can provide a better understanding of continuous climate change and its effects. New observational methods and experimental ideas are needed to achieve this aim. Various studies indicated that the decline in the soil concentration results in higher atmospheric carbon concentration. In soil organic carbon misplacement is mostly because of the alterations in the soil's composition and structure. Increased soil concentration will also lead to increased CO2 emission from the soil. So, carbon sequestration from the soil is a leading pathway to mitigate climate change. More research work is needed to counter the large scale carbon emissions. Management practices, precautionary measures should be taken to minimize the disastrous effects of human activities on soil structure. Land misuse should be minimized and restoration processes must be carried out for better crop production and to avoid/minimize soil erosion. Some issues related to the carbon cycle and carbon sequestration from soil should be addressed which are as following:

1. Which ecosystem has large carbon concentrations and how to identify it?
2. RMP (recommended management practices) for carbon sequestration from farmland and other soils.
3. What are better processes for soil carbon sequestration, their cost-effectiveness, and their precision and accuracy?
4. Association between soil and water's procedures in response to greenhouse gases.
5. What would be outcomes of any changes in the global carbon pool?
6. How features and quantity of soil organic carbon effect air water and soil's quality?
7. What will be expenses of carbon isolation from soil under various conditions like vegetation, water, and soil management implementations?

All these issues should be clearly understood in order to control and limit the disastrous effects on climate. More research work is required for understanding carbon scattering in various ecosystems, its contribution to global warming and the procedures to minimize climate changes.

1.7 Conclusion

The carbon cycle is a natural cycle that maintains the carbon flow among different reservoirs. Carbon circulation occurs in soil, terrestrial ecosystems, aquatic areas and within inland water resources. Carbon stock is present in the soil as soil organic carbon which is decomposed by various microbes and other chemical reactions. Some of the carbon is utilized by the plants and remaining is released into the atmosphere. Due to continuous changes in global temperature, carbon cycle became disrupted. The carbon concentration of soil is declining as more and more of the soil organic carbon is becoming a part of the atmosphere. The release of CO_2 exceeding the threshold limit raised the global temperature which resulted in global warming. Global warming further affects the Carbon cycle which causes an increased emission of CO_2 in the atmosphere. Anthropogenic activities are a major source of greenhouse gases. Greenhouse gases enhance the Earth's temperature. There are various greenhouse gases like SO_2, CO_2, nitrous oxide, ozone, and CFCs. CO_2 is one of the enormously discharged gas into the atmosphere. Naturally, carbon dioxide discharges into the atmosphere through plants, humans and animal's respiration, soil respiration and through natural carbon cycles from terrestrial and aquatic ecosystems. Various anthropogenic activities like tropical deforestation, land misuse, biomass burning, soil erosion, and industrial development discharge a huge amount of CO_2 in the atmosphere which results in increased temperature which melts glaciers and causes flooding. Global warming has disastrous effects not only on the lives of human beings but also on animals and plants. The density of animals got is changing globally due to climate change as they move toward the areas with a more favorable environment. Plants characteristics, development time, growing time is also changing with climatic changes. Since soil's carbon is responsible for the huge discharge of CO_2 into the atmosphere so one way to mitigate climate change is to isolate/sequester carbon from the soil. Land use in a better way by implementing suggested management instruction can have considerable results for soil's carbon sequestration. Soil's carbon sequestration not only decrease the emission of CO_2 discharge into the atmosphere but also maintains a natural carbon pool. It betters soil quality and magically enhances biomass yield. So, carbon isolation from the soil is the best way to diminish temperature alterations and to improve soil quality which is a natural homeland for plants and other living organisms.

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Chapter 2
Agricultural Land Degradation: Processes and Problems Undermining Future Food Security

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Abstract Despite significant progress in increasing agricultural production, meeting the changing dietary preferences and increasing food demands of future populations remain significant challenges. This is especially the case in developing countries. Climate change and variability, unstable markets, and shrinking arable land resources that result from urbanization and industrialization represent additional challenges. In many countries – especially those with dense populations and/or diverse ecosystems in need of conservation – expanding agriculture to new lands to increase production is not an option. Conversely, where farmers' practices result in land degradation and deterioration of soils and natural resources upon which future productivity depends, urgent research and policy attention is needed to arrest and reverse declines in land degradation and adverse soil quality in consideration of mounting global demands for agricultural goods. This chapter provides a synopsis of agricultural land degradation issues while providing potential solutions to reverse

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_2

soil quality decline through an understanding of integrated land management practices. In addition to methodologically describing the impacts of land degradation on agricultural productivity, the chapter provides up-to-date information for the specialists in the fields of agricultural development, soil science, topography, economics, and ecological management. Options for appropriate policy frameworks to mitigate the degradation of agricultural land at the international, regional and national levels are discussed and proposed.

Keywords Food security · Drought · Land degradation · Salinity · Erosion · Soil contamination · Soil acidity · Sustainable ag riculture

Abbreviations

Cd	cadmium
Cu	copper
EC	electrical conductivity
Fe	iron
FAO	Food and Agricultural Organization
GHG	greenhouse gas emissions
GLADA	An on-going assessment within the FAO's Global Assessment of Lands Degradation and Improvement project
GLASOD	The Global Assessment of Soil Degradation
GR	glutathione reductase
GSH	glutathione
IBSRAM	International Board for Soil Research and Management
MNR	Ministry of Natural Resources

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Ni	nickel
Pb	lead
POX	peroxidase
SOD	superoxide dismutase
SOM	Soil organic matter
UN	United Nations;
UNEP	United Nation Environmental Programme
UNISDR AF	United Nations Office for Disaster Risk Reduction – Regional Office for Africa
UNNC	United News Centre report
US-EPA	United States Environmental Protection Agency
WWF	World Wildlife Fund
Zn	zinc

2.1 Human Population in the World and Present and Future Food Demand

The recent United Nations (UN) population projections (medium variant) anticipated that the population is expected to grow from 7 billion in 2010 to a projected 9.8 billion by 2050 (United Nations 2015; Timsina et al. 2018; Searchinger et al. 2019). Despite this trend, the absolutized population growth rate is expected to slow considerably in the future relative to the past 50 years, while still cumulating at a total above nine billion. The most of this increase in population occurs in developing countries, with the relative increase (120%) is expected in the world's least developed economies (Woods 2019), with significantly larger rates of urban increase relative to rural population growth. More than 70% of the world's urban population is expected to be increased by 2050 (United Nations 2015).

Therefore, to supply sufficient calories and nutrients to a larger, increasingly urban and what is anticipated to be a more affluent population with preferences for animal-based proteins, food production must be increased by 70% by 2050 (FAO 2011; Searchinger et al. 2019). The annual cereal production should be increased to 3 billion tonnes (tons) (about 50%) from the current production of 2.1 billion tons, while the annual meat production should be increased by over 200 million tons to meet an expected demand of 470 million tons, unless diet preferences change and less meat is consumed, which may considerably lower total cereal and meat demands (Borlaug 2007; FAO 2009, 2011; Tilman et al. 2011; Bruinsma 2011; Guillon et al. 2012; Alexandratos and Bruinsma 2012). However, in terms of food energy, presently approximately one billion people across the globe are not meeting even the basic food needs. Living in so-called 'hunger hotspots', which are often ecologically fragile and where agriculture competes with other land uses, much of the populations have to cope with conditions of high population density, loss of arable land, and deteriorating ecosystems (FAO 2009). Some experts (Cassman 1999; Godfray et al. 2010; Tilman et al. 2011) have underscored the above future challenge as especially disconcerting because at present levels of agricultural production and subsequent food waste, simply meeting current demand while also assuring social equity in access is a considerable challenge. It is generally recognized that demands of nourishment are increasing faster as compared to the food production or systematic reductions in, and redistribution of food, that is wasted. Therefore to improve alternative agricultural approaches to meet the increasing future food demand for the given population and their consumption trends, researchers and policymakers progressively highlight their urgent needs (FAO 1992; Yamaguchi and Blumwald 2005; Galvani 2007; Howden et al. 2007). Investments in low environmental impacts and productive agricultural technologies and policy strategies are needed to respond to these crucial problems without degrading land and natural resource quality *viz.,* soil and water (Galvani 2007). Searchinger et al. (2019) projected that to feed the growing global population by 2050, the gap (compared with the land in 2010) in the projected the global agricultural land area will be 593 million hectares (ha) (double to the country of India) to produce the desired crop and pasture yields. The earth's ten most populated countries have already faced a decreasing trend in per capita arable land (Gomiero 2016). For example, the most populated and poorest countries, particularly in South Asia, have already faced problems meeting food demand for several key staples from existing cropland without expanding agriculture's footprint. During the initial stage of agriculture (about 8000–10,000 years ago), crop cultivation and livestock rearing had been the prime reasons for ecosystem changing and land degradation (Millennium Ecosystem Assessment 2005). Today, more than 1/3 of the planet's land and almost 1/2 of the world's under the vegetation is being used for food production (FAO 2011; Foley et al. 2011). To feed the increasing population, intensive agriculture is expanding especially in developing countries since it is the leading driver for changes in biodiversity, particularly land degradation (Millennium Ecosystem Assessment 2005).

According to the new global Land Cover Share-database (GLSD) (Guimarães et al. 2013), 13% area is under croplands and another 13% is under grasslands, the latter often used for grazing. Both peer-reviewed and policy literature have highlighted soil degradation as a major concern (Karlen and Rice 2015). In the meantime, 35 million km^2 of the land area (24%) across the globe have already been degraded (Gao and Liu 2010). Considering these urgent issues, this chapter provides an outlook of the causes, types and consequences of land degradation, while suggesting potential solutions that may help to increase productivity while arresting negative environmental externalities.

2.2 The Land Degradation Concept

To define and describe the concept of land degradation, a wide range of terms are being used in the literature, often with distinct disciplinary-oriented meanings, which lead to confusions among disciplines. Some conjoint terms are land degradation, soil degradation and desertification, though there is a clear dissimilarity between 'soil' and 'land' (Eswaran et al. 2001). In arid, semi-arid and sub-humid areas, land degradation generally occurs due to the desertification as a result of the anthropic activities (UNEP 1992). Additionally, in temperate humid regions and the humid tropics, severe land degradation can also be the result of the anthropic activities. The connotation of degradation or desertification relies on a number of physical and biological factors that decline the primary productivity. Similarly, the misunderstanding is further exacerbated in using the term ‘dryland’. For these reasons, Eswaran et al. (2001) long ago proposed that to develop a precise, objective, and unambiguous definition of land degradation and to standardize the terminology. This is required for its applicability to diverse soil textures and agro-climatic conditions, reduce confusion in the use of the concept, and increase communication among various disciplines.

In the World Soil Charter, land degradation is defined as the deleterious loss of land functions, either partially or totally, resulting from modifications of its properties by humans (FAO 2015a). FAO (2019) reported that once soils begin to experience degradation, they fail to provide anticipated ecosystem services for users (Lehman et al. 2015). Land degradation, in turn, refers to a deterioration of soil quality over time, affecting the capacity of a given piece of land, landscape, or region to maintain net primary productivity (UNEP 1992). In an advanced stage of degradation, ecosystems may no longer be functionally capable of tolerating, storing, and reusing water, nutrients and energy, all of which affect primary productivity and biodiversity (Oldeman et al. 1991).

2.3 Historical Land Degradation in the World

Land degradation is the consequence of physical disruption of the soil by erosion affected by water, wind, gravity, or tillage. Changing the physical, chemical and biological environment of soils through indecorous utilization of land (including agriculture), acidification, salinization, or contamination are also important (Lal 2015; Chalise et al. 2019). Degradation is typically associated with human land use activities that affect erosion, decomposition, leaching, nutrient imbalance and soil organic matter (SOM), and with the suppression or elimination of soil biota through strategic management practices. In addition, degradation is often associated with a reduction in soil pore space through structural and physical modifications including tillage and compaction, in addition to other stresses. Soil surface sealing and crusting can also result from agricultural practices and also through infrastructure and urban development activities (Lal 2015; Chalise et al. 2019).

Land degradation has been one of the prevalent menaces to soil productivity since the initial stage of agriculture (Sullivan 2004; Utuk and Daniel 2015). The evidence provided by Scherr (1999) revealed that a large-scale soil degradation occurred over the past 5000 years across the globe. For example, Nkonya et al. (2016) estimated that 2 billion ha of land that were biologically productive previously had been irreversibly degraded over the past millennium. Similarly, Utuk and Daniel (2015) reported that degradation of agricultural land has been one of the most international agenda in the twenty century and also will remain a burning issue in the next (twenty-first) century. About 25% land in the world is under the most degradation trend, 36% under moderately degradation trend, 8% under moderately and slightly degradation trend, 8% land is under improvement and 18% are bare lands, and remaining 2% area is embodied by water (Reynolds et al. 2007; FAO 2011; Bindraban et al. 2012; Gomiero 2016).

Rozanov et al. (1990) analyzed the changes in the global terrestrial biosphere and reported a humus loss rate of about 25.3 million tons year^{-1} since the dawn of agriculture over 10,000 years ago. Among the losses, 300 million tons year^{-1} were accelerated during the past three centuries and 760 million tons year^{-1} during the past five decades. About 16% of the stock of organic soil carbon could have been lost within these time-frames. However, due to secondary salinization, 100 million ha of irrigated land alone have succumbed to degradation over the past three centuries and another 110 million ha of agricultural land resulting in reduced productivity.

The Global Assessment of Soil Degradation (GLASOD) indicated that during the last 40 years, about one-third of global total arable land was permanently damaged in some way by soil erosion, with continued rates of erosion estimated at approximately 10 million ha year^{-1} (Pimental et al. 1995). Early estimates were that India faced considerable challenges, with about 18.5% of total global soil erosion occurring there. Further, it has been judged that about 5.3 Pg of soil was lost per annum in India prior to the 1980s (Dhruvanarayana and Babu 1983). This effort was put into place to provide continental estimates of post-World War-II severity and geographic spread of land degradation while also creating awareness and quantifying the status of soil degradation. More than 250 scientists worked together to prepare 21 regional soil/land maps showing the amount and harshness of human-induced soil degradation. Importantly, a common methodology was employed in these efforts. Following clarification of physiographic units into groups with relatively standardized geography, climate, soils, vegetation and land uses, GLASOD evaluated each unit for its gradation, degree, and the measurable current rate of degradation. Anthropogenic causes of degradation were also evaluated and ranked according to their severity and importance. A 1:10 million scale GLASOD map of each unit was prepared, which was digitized and connected to a uniform database. Since the development of the GLASOD maps relied on expert assessment, they may have had some unsubstantiated biases and were certainly based on expectations, although they did represent an important early effort in the systematic study of land degradation. Through GLASOD, scientists established that 1.97 billion ha of land (23% of global land) had been degraded.

2.4 Global Status of Land Degradation

About 30% of the total global lands and about three billion populations in the world face the adverse effect of land degradation. Foregone profits in agricultural productivity that result from land degradation are estimated at an annual cost of about US$300 billion; in Sub-Saharan Africa, the total cost is the largest (22%) (Nkonya et al. 2016). More recently, the German Environment Agency (UBA 2015) informed that about 10 million ha of arable land globally is rendered unproductive on annual basis. In an effort to visualize this more meaningfully, they equated this area approximately 14 million football fields. The UBA also reported that approximately 25% of the soils used for agricultural and livestock production activities had significantly reduced amounts of humus and essential nutrients when compared to the previous quarter-century. This renders them unsuitable as cropland. The primary reasons reported for these trends included (a) swidden agriculture, (b) excessive and inappropriate tillage, and (c) traditional agricultural technologies that are poorly adapted to local circumstances.

Assessment of the quality of land currently utilized for cropping is also an issue, as it is crucial to understand where and how much land is cropped in relation to land degradation (Alexandratos and Bruinsma 2012; Conway 2012; Lambin et al. 2013; FAO and ITPS 2015). In the late 1990s, modeling efforts estimated that about 25% of agricultural land was degraded in some way (FAO 2011; Bindraban et al. 2012; Rekacewicz 2008). FAO (2011) has been pointed out that there is a robust relationship among poverty and land degradation; this underscores the need to slow soil degradation through the edition and implementation of suitable farm management approaches that can improve soil quality.

Estimates of total land (km^2), agricultural land (km^2), arable land (1000 ha) and Global scale estimates of degradation (million ha) in Asia, Africa, Europe, North America, South America and Australia and the Pacific are presented in Table 2.1. Continent-wise sources of estimation revealed that Asia is the most degraded continent, followed by Africa, North America, South America, Australia and Pacific; while Europe is least degraded. A detailed description of degraded lands in the world is given in the following sub-sections:

2.4.1 Status of Land Degradation in Europe and Central Asia

Analysis of current data on soil degradation shows that the degree and intensity of negative processes are considered for analysis and reporting of soil degradation in Europe and Central Asia are characterized by diverse soils (Nachtergaele et al. 2011). Western European countries include the EU Member States and can be characterized by policy conducive to a higher degree of soil care and limitation of intensive agricultural practices that accelerate degradation, although this varies across sub-regions (Euronews Reports 2015; European Commission (Press release) 2017). Some of the main pressures on land in Western Europe include increasing urbanization and land conversion, unsustainable agricultural practices, and industrial and traffic development. Competition for land and conversion of crop acreage to urbanization poses a major threat to soil. Approximately 80% of European inhabitants are expected to live in cities by 2020 (Gardi et al. 2015; Euronews Reports 2015). Increasing urbanization has consequences for agricultural land; between 1990 and 2006, one-quarter of EU member states were estimated to have lost the potential

Table 2.1 Total land (km^2), agricultural land (km^2), arable land (1000 ha) and degraded land (million km^2) across the globe

Continent	FAO (2015a, b, 2017)			[d]Global-scale estimates of degradation (million ha) estimated by several sources							
	[a]Total land km^2 (2017)	[b]Agricultural land km^2 (2015a, b)	[c]Arable land ('1000' ha) (2015a, b)	GLASOD	GLADA	Cai et al. (2011)	Campbell et al. (2008)	Dregne and Chou (1992)	FAO Pan-tropical Landsat	FAO TerraSTAT	Overall estimation by several sources
Africa	29,379,932	10,992,245	235,118	321	660	132	69	1046	9	1222	3459
Asia	47,358,137	18,809,446	617,982	453	912	490	118	1342	12	2501	5828
Central America & the Caribbean	726,510	291,511	10,216	–	–	–	–	–	–	–	–
Europe	6,533,346	2,881,078	174,084	158	65	104	60	94	[g]	403	884
North America	20,595,330	5,754,596	218,783	140	469	96	79	429[d]	[g]	796	2009
Australia and Pacific	8,480,070	3,792,324	47,256	6	236	13	743	376	[g]	368	1742
South America	17,366,742	6,192,659	142,306	139	398	156	69	306[b]	56[e]	851	1975
World total	139,629,401	53,015,125	1,532,618	1216	2740[f]	991	470	3592	76[g]	6140	12,409

GLASOD The Global Assessment of Soil Degradation, *GLADA* An on-going assessment within the FAO's Global Assessment of Lands Degradation and Improvement project

[a]Total land area is a country, excluding inland water, national claims to continental shelf, and exclusive economic zones. In most cases the definition of inland water bodies includes major rivers and lakes

[b]Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures

[c]Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow

[d]Does not include the Caribbean

[e]Includes some Caribbean countries

[f]Total based on country areas listed in Table 1 of Bai et al. (2008), and does not match global total listed in the same source (3506 million ha)

[g]Non-tropical continents not included in this study

production of an equivalent of six million tons of wheat to urbanization (Gardi et al. 2015).

Eastern Europe (including Belarus, Moldova and Ukraine), Russia and Turkey can be described as experiencing a rapid shift to intensified agriculture and unsustainable agricultural practices. Over- exploitation of the most fertile soils and abandonment of less productive lands have been cited as important concerns (Euronews Reports 2015; European Commission (Press release) 2017). In Eastern Europe, Russia and Turkey, the major driver of soil degradation is increasingly rapid economic transition that on one hand offers new market opportunities to farmers but on the other hand also opens the door to widespread use of unsustainable land management practices. Environmental contamination from industrial, mining, and petroleum extraction represent additional concerns. In Russia, approximately 26% of the country's farmland areas are estimated to suffer from medium to high levels of water erosion (Ministry of Natural Resources 2006). More than 56 million ha of agricultural lands are losing SOM (Shoba et al. 2010), where the area under the salt-affected soils is around 54 million ha (3.3% of Russia's overall land area).

In Ukraine, the total area is about 60.4 million ha, of which 70% is agricultural land and 81% is arable land; as a result with this intensive agricultural land use, the country is severely facing serious environmental hazards, particularly soil erosion (Saiko 1995). Laktionova et al. (2010) estimated that about 1/3 of total agricultural land (14.4 million ha) in Ukraine is affected by water and wind erosion. Saiko (1995) and Novikova (2009) revealed that the annual loss of soil in Ukraine is approximately 600 million metric tons, where more than 20 million metric tons is humus. In Moldova, an estimation revealed that 1/3 of arable lands (approximately 840,000 ha) are affected by water erosion (Leah 2012). In the territory of Belarus, about 467,000 ha lands are underwater erosion, while another 89,000 ha land areas are lost due to wind erosion. Similarly, in Turkey, 79% of the total land area is degraded due to wind erosion (Senor and Bayramin 2013). On the other hand, 50% and 30% of land in Turkey is affected respectively by natural and irrigation-induced soil salinity, whereas 0.4% and 8% are alkaline or saline-alkaline soils, respectively (Senol and Bayramin 2013).

In Western Europe, farmlands are under pressure from a long history of relatively intensive tillage, the use of heavy farm machinery that can cause compaction, and over- and/or misuse of nitrogen (N) and phosphorus (P) fertilizers. These factors can result in soil erosion, loss of SOM, soil compaction, greenhouse gas (GHGs) emissions, as well as water pollution. When poorly conducted, tillage practices can result in soil erosion by water and wind. Tillage can also excessively pulverize and expose the soil to aeration that results in oxidation and decline in organic soil matter if not balanced with organic inputs. According to Jones et al. (2011), 105 million ha in Western Europe were affected by water erosion and another 42 million ha affected by wind erosion in the 1990s. Some 45% of the soils in Western Europe also have very low SOM status (< 2% organic carbon). Reasons for low SOM as reported by Jones et al. (2011) include: (a) conversion of natural vegetation to arable land, (b) inappropriate and overly-repetitive tillage and deep ploughing, and (c) drainage of peat soils are particular problems. In addition to these, Kibblewhite et al. (2005)

reported other reasons for low SOM such as: (a) unbalanced and excessive fertilizer use, (b) shorter fallows or crop rotation without appropriate cover or scavenger crops, (c) soil erosion and (d) wildfires are also concerns.

Crucially, SOM also affects the resilience of cropping systems due to climate variability. Bearing in mind of the EU-27 Member States, soil stocks are projected to store between 73 and 79 billion tons of carbon mostly in the peat and forest soils of Sweden, Finland and the United Kingdom (Schils et al. 2008). This is correspondent to nearly 50 times the total yearly GHGs emissions from those countries. Conversely, exhaustive and constant use of arable land for agricultural production can result in a decline in these stocks, in turn affecting GHGs. In 2009 alone, farming activities in Europe emitted an average of 0.45 tons of CO_2 ha^{-1} (EEA 2011), while there is no widely agreed-upon record of peat stocks in Europe. Report by Schils et al. (2008) estimated that > 20% of the region's peatlands have been drained and converted into agricultural production. This is relative to less than 1% of these lands maintained for peat extraction.

The Central Asia (CA) states including Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan and the Caucasus encompasses (CAC) Armenia, Azerbaijan, and Georgia. Both regions have the greatest extent and severity of soil degradation due to physical geography and climatic variation and anthropogenic factors and also due to their biophysical conditions, including mountainous topography and arid climate (Euronews Reports 2015; European Commission (Press release) 2017). The key burden on soils in both regions is unsustainable land and water management, particularly through inefficient irrigation and unsustainable agricultural practices (e.g., mono-cropping of cotton, inappropriate use of fertilizers, inadequate soil care, overgrazing of pastoral lands, etc.), resulting in soil erosion, SOM loss, nutrient depletion, and secondary salinization. Eroded soils in the CAC cover 35–43% of total agricultural lands, where in CA over 30 million ha of land area is affected by water erosion and about 67 million ha is degraded by wind erosion. In Uzbekistan, agricultural land is affected by water erosion up to 80% and in Tajikistan is between 60% and 97% (CACILM 2006).

Saline and sodic soils are widespread in CAC, also in CA, where 40–80% of irrigated lands are salt-affected and/or waterlogged (FAO 2015b). The area of saline soils in Kazakhstan is 41% of the national territory (about 111.55 million ha) (Borovskii 1982). However, the majority of this area has naturally saline, due to the presence of marine sediments. In Uzbekistan about 46.5% (about 20.8 million ha) of the country's territory is under salinity (Kuziev and Sektimenko 2009), due to the shallow groundwater table (less than 2 m below the soil surface). As a result, about 1/3 of irrigated lands in Uzbekistan are affected by excessive soil salinity (Rakhmatullaev et al. 2012).

Similarly, in Turkmenistan salt-affected soils (particularly west close to the Caspian Sea) are also widely distributed and cover about 28.7% of the total area of the country (about 14.1 million ha) (Pankova 1992). As a result, up to 68% of the total area of irrigated lands in Turkmenistan is affected by excessive salinity (Rakhmatullaev et al. 2012). The area of salt-affected soils in Azerbaijan is about 5.9% of the country's territory (about 510,000 ha) (Ismyilov 2013). About 45% of

Table 2.2 Vulnerable Asian countries at risk of desertification

Countries	Total land area (km^2)	Vulnerability to desertification							
		Low		Moderate		High		Very high	
		Area	%	Area	%	Area	%	Area	%
Afghanistan	647,500	2954	0.46	39,088	6.04	43,838	6.77	436,480	67.41
Bangladesh	133,910	85,163	63.60	0	0	0	0	0	0
Bhutan	47,000	1407	2.99	0	0	0	0	0	0
Brunei	6627	0	0	0	0	0	0	0	0
China	9,326,410	262,410	2.81	239,107	2.56	65,638	0.70	72,214	0.77
India	2,973,190	1,277,328	42.96	744,148	25.03	206,317	6.94	165,912	5.58
Indonesia	1,826,440	29,596	1.62	46,290	2.53	5289	0.29	232	0.01
Japan	374,744	0	0	0	0	0	0	693	0.18
Cambodia	176,520	45,731	25.91	118,155	66.94	0	0	0	0
Laos	230,800	48,963	21.21	35,386	15.33	0	0	0	0
Malaysia	328,550	0	0	0	0	0	0	0	0
Mongolia	1,565,000	26,345	1.68	40,511	2.59	19	0	2104	0.13
Myanmar	657,740	130,903	19.90	140,387	21.34	20,630	3.14	13,477	2.05
Nepal	136,800	20,131	14.72	8698	6.36	0	0	228	0.17
North Korea	120,410	0	0	0	0	0	0	0	0
Pakistan	778,720	31,474	4.04	39,605	5.09	17,032	2.19	181,503	23.31
Papua New Guinea	452,860	4892	1.08	8175	1.81	27	0.01	0	0.00
Philippines	298,170	20,952	7.03	16,621	5.57	1708	0.57	0	0.00
Singapore	638	0	0	0	0	0	0	0	0
South Korea	98,190	0	0	0	0	0	0	0	0
Sri Lanka	64,740	6337	9.79	24,393	37.68	3421	5.28	0	0.00
Taiwan	32,260	2902	9.00	201	0.62	277	0.86	0	0.00
Thailand	511,770	90,241	17.63	320,581	62.64	7265	1.42	0	0.00
Vietnam	325,360	47,516	14.60	59,238	18.21	375	0.12	0	0.00
Total	21,114,349	2,135,245	261	1,880,584	280	371,836	28	872,843	100

Data adapted from Eswaran et al. (2001) and Miyan (2015)

irrigated lands in Azerbaijan suffer from salinization processes (RAE Aliev 2018). Table 2.2 presents the vulnerability of land to desertification in some Asian countries. Twenty-five percent of the region is affected in some way by desertification processes. This has raised concerns about environmental change and resulting social and political instability (Ma and Ju 2007).

2.4.2 *Africa*

The African continent covers more than 3.01 × 109 ha and has long been recognized as being threatened by land degradation. Recent estimates are that the African continent has ~65% of the world's degraded lands (Bationo et al. 2006; Msangi 2007).

The World Bank (Thiombiano and Tourino-Soto 2007) has estimated that some 485 million people in Africa are in some way experiencing the effects of land degradation (Zeidler and Chunga 2007), with estimates that loss of ecosystem services from degraded land result in lost productivity and other problems at a cost of US$9.3 billion annually (Sonneveld 2002). Causes of degradation include inappropriate farm practices, swidden agriculture and deforestation, in addition to lateral weathering processes. In addition, another causal driver of land degradation in Africa is unstable land tenure, in part related to social conflicts and wars, and including refugee population concerns (Thiombiano and Tourino-Soto 2007; Zambrano-Monserrate et al. 2018).

Considering the mechanisms of land degradation, soil and water erosion are estimated to affect 80% of Africa's soils; in the Sahel belt south of the Sahara in particular, soil crusting can increase run-off and sheet erosion (Perez 1994). In Nigeria, water erosion has been estimated as contributing up to 30 million tons of soil lost year^{-1} (Oyegun 1990; Warren et al. 2003). In semi-arid and arid zones, wind erosion contributes to a large extent to soil transport (Sterk 1996). High wind speed > 10 m s^{-1} in Burkina Faso has for example been estimated at contributing 329 t ha^{-1} year^{-1} in soil loss, largely from June to August prior to the onset of rains (Bielders et al. 1998; Sivakumar and Ndiang'Ui 2007).

2.4.3 South America

Land degradation in South America results from water and wind erosion, desertification and soil salinization. Problems with fertility loss, acidification, poor drainage and soil compaction are common, as is the loss of structure and functional biodiversity of soils in agricultural and livestock rearing areas (Santibáñez and Santibáñez 2007). In Chile, for example, soil erosion processes are a problem on more than 60% of the country's land area (Ellies 2000). On the western 'faldeo' slopes of the Andes mountains, erosion processes are an issue for unstable soils in 'Yungas' soils that stretch from Colombia to Argentina. In Argentina, the exportation of agricultural products such as grain and meat is considered as the cause of land degradation (Bouza et al. 2016). In Argentina, soil salinization is noted as a constraint affecting both irrigated and drylands (Williams 1999; Bouza et al. 2016). Bolivia, however, appears to be a 'hotspot' for land degradation. Between 1954 and 1996, Bolivia's land area experiencing erosion was reported to have increased from 236,833 square kilometers (km^2) to 428,700 km^2 (Benites et al. 2003). In Brazil, larger-scale contemporary land degradation started over four centuries ago with the arrival of Europeans, changes in land use and colonization processes. Deforestation dramatically increased in the nineteenth century as demand for sugarcane and coffee increased, causing rapid changes in land use (Simmons et al. 2002; Santibáñez and Santibáñez 2007). More recently, Brazil's import and production of agricultural machinery increased by 2000% between 1975 and 1995 (Merten 1996); where tractors are equipped with inappropriate soil engaging implements or are used improperly, soil degradation can result.

Accurate estimates of soil loss are difficult to acquire in Columbia. In the 1990s, however, changes in land use and cultivation patterns resulted in an estimated 48% of Colombian territory being subjected to some form of degradation, of which 14.2% and 10.8% were judged as being very severe or significant, respectively (Sivakumar and Ndiang'Ui 2007; Jaramillo-Mejía and Chernichovsky 2019). Soil degradation is considered among the more serious environmental problems of Ecuador (White and Maldonado 1991), due to the deforestation. Estimates are that >60% of Ecuador's alpine Paramo zone is impacted by human activities, with most land converted to agricultural uses, primarily for grazing (Tapia-Armijos et al. 2015). In Peru, land degradation is occurred due to human involvement, including demographic burden and indecorous land utilization (Guevara and Milla 2007). Logically, erosion is most noticeable in mountainous areas. At a national level, about 60 million ha, or 55% of Peru's landmass are estimated as being subjected to some form of erosion. In Venezuela, degradation of land is mainly linked to water erosion, soil surface sealing, compaction, salinization, and sodification (Hugo 2006; Endonca-Santos et al. 2015). Deforestation in Venezuela is another concern that results in land degradation; conversion of forests to other land uses are principally linked to agricultural expansion. Limitations of Peru's political system and problems with land and agrarian reform processes are also contributing factors that encourage forest loss and consequent degradation (FAO 2000).

2.4.4 North America

In North America, soil degradation is generally linked with improper agricultural and livestock land-use practices, both associated with wind and water erosion, in addition to urbanization. In response, efforts to arrest soil quality decline have evolved to highlight integrated management techniques that in many circumstances include use of cover crops or crop residue retention on the soil surface to diminish raindrop effect, maintain to higher infiltration rates, and also increase soil water storage (Sivakumar and Ndiang'Ui 2007; Santibáñez and Santibáñez 2007; Endonca-Santos et al. 2015).

2.5 Areas Vulnerable to Desertification

An important and often discussed form of land degradation, desertification happens mainly, but not solely, in semi-arid climatic zones. The arid and semi-arid zones of Africa are predominantly susceptible, as are characterized by soils with fragile structures, increasing population densities and agricultural intensity (Thiombiano and Tourino-Soto 2007). Estimates are that 33% land surface in the world

Table 2.3 Human-induced desertification matrix for risk assessment

Vulnerability class	Population density (persons km²)		
	< 10	11–40	> 41
Low	1	3	6
Moderate	2	5	8
High/Very high	4	7	9

Source: Reich et al. (1999)
1 = low risk; 2, 3 = moderate risk; 4, 5, 6 = high risk; 7, 8, 9 = very high risk

(42 million km^2) is subjected to desertification, where a number of people directly or indirectly contribute to the desertification processes (Eswaran et al. 2001). Earlier study reported by Reich et al. (1999; Table 2.3) provides some estimates for Africa.

Table 2.3 provides a metric for assessing vulnerability and population density in reference to desertification. High population densities in areas vulnerable to desertification entail high risks for food security and livelihoods. On the contrary, a low population density in locations where susceptibility is low will result in lower risk, ceteris paribus. The Mediterranean countries such as North Africa's Maghreb are considered to be highly susceptible to desertification. Erosion in parts of Morocco has become so severe that the petrocalcic horizon of some Palexeralfs soil can be found exposed at the surface. Considering the Sahelian region, which for many is synonymous with desertification, there are particular locations with a very high risk of rapid desertification processes. Population densities in West Africa are also on the rise (Thiombiano and Tourino-Soto 2007). In 2015, the population in West Africa was 367 million (5% of the world's population) (UN 2015). This is a fivefold increase in population since 1950 when 73 million people lived in the region (Ouedraogo et al. 2010). In environmentally fragile locations with dense populations, land degradation has become a major concern (Thiombiano and Tourino-Soto 2007; Sivakumar and Ndiang'Ui 2007).

An estimation indicated 2.5 million km^2 of land are under low risk. A similar number (2.9 million km^2) is considered to be under high risk for the desertification (Eswaran et al. 2001). The Sahelian region and south of the Maghreb (West Africa) are considered to be on the margins of the Sahara. They occupy about 5% of Africa's landmass. Roughly 22 million people (2.9% of the total population) lived in this area at the end of the millennium. Conversely, the low, moderate, and high vulnerability classes described in the tables above were estimated to occupy 14%, 16%, and 11%, respectively. When summed, desertification processes in these areas were estimated to impact about 485 million people (Eswaran et al. 1997a, b).

2.6 Types and Extent of Land Degradation

The speed of land degradation is influenced by a number of physical, chemical and biological processes that – when considered from an agricultural perspective, negatively influence the potential productivity of land (Lal 1994). About 494 million ha in Africa are in some state of physical and chemical degradation. South of the

Sahara, roughly 65% of agricultural lands have been impacted by some form of chemical and physical degradation caused by human and climatic factors (Oldeman et al. 1991). The severity of degradation is a function of terrain deformation, soil mass movement by water and/or wind, compaction and soil crusting, subsidence and waterlogging, in addition to the loss of essential nutrient and organic matter, salinization and alkalization, and acidification. Kirui and Mirzabaev (2014) and Shahid et al. (2018) stated that overgrazing, deforestation, inappropriate use and management of agricultural soils, as well as unmaintainable use of natural resources, increase 49%, 24%, 14% and 13% of soil degradation processes. Dregne (1990) indicated that 33 countries within Africa including Algeria, Ethiopia, Ghana, Kenya, Lesotho, Mali, Morocco, Nigeria, Swaziland, Tanzania, Tunisia, Uganda and Zimbabwe are experiencing the severe land degradation (Utuk and Daniel 2015). Dregne and Chou (1992) also estimated that 73% of dryland soils were in some way degraded. Fifty-one percent of these soils were severely degraded. Considering land-use type, 18%, 71% and 74% of irrigated, rainfed and grazing lands within Africa's arid climates were estimated as degrading in some way. The different types and extent of degradation experienced globally are detailed below:

2.6.1 Saline and Sodic Soils

Soil salinity can be measured by the concentration of soluble salts found in a given volume of soil. Salts are predominately composed of Cl^- (chlorides) and SO_4 (sulfates) though carbonates and bicarbonates of sodium, calcium, magnesium and other ions also occasionally occur. Soil salinity is measured by electrical conductivity, which is soil's ability to conduct an electrical current and exceeds four deciSiemens per meter (dS m^{-1}) (Shahid et al. 2018). Soils that experience natural salinity are referred to as primary saline soils. Soils with secondary salinity, however, experience salinization processes from land-use changes and management, particularly from improper irrigation and drainage. Salinity is detrimental to plants and can cause crop failure. The effects of salt include a decrease in plant available water because osmotic pressure in the soil is positively related to electrical conductivity. Toxicity from individual salts can also result, as well as ionic imbalances that decrease nutrient retrieval from the soil. Where salt concentrations are high, moisture stress results from high ionic concentrations. Soil structure can also deteriorate, especially in sodium dominant soils (FAO 1988; Tavakkoli et al. 2010, 2011).

Soils that are saline contain neutral soluble salts in the form of sodium chloride and sodium sulfate. These salts can adversely affect crop productivity. Saline soils may also contain considerable amounts of sulfates of calcium and magnesium, as well as chlorides (Szabolcs 1974). Soils that are high in Na_2CO_3 and that exhibit alkaline hydrolysis are at times also referred to as 'Alkali' (Silvertooth 2001). In addition to chemical composition, both physical and biological properties further differentiate these two main groups of salt-affected soils, which also vary in their geographic distribution. These differing characteristics also render each soil type as requiring customized approaches for reclamation and agricultural utilization. When not subjected to anthropomorphic use, the different types of sodium salts tend to not occur in isolation. Rather, salts capable of alkaline hydrolysis or neutral salts can play an important part in soil formation (Szabolcs 1974).

Soil salinity is a global land degradation concern (Zhu 2001; Corwin and Lesch 2003). Various United Nations agencies estimated that there are at least 4 million km^2 of salinized land globally, with crops grown on 20% of agriculturally productive soils experiencing some form of saline stress (Ravindran et al. 2007; Rozena and Flowers 2008). These conditions have important economic implications. Most crops are sensitive to salinity; the cost of salinity to agriculture estimated by foregone yield has been conservatively estimated at around USD $12 billion (Ghassemi et al. 1995).

Early attempts to map the extent of salt-affected soils globally were made by Szabolcs (1974) and Massoud (1977) using the FAO's global soil maps as base information (Table 2.3). The FAO estimated the global extent of saline soils at approximately 397 million ha. Sodic soils were estimated at 434 million ha. Considering 230 million ha of irrigated land, 19.5% were estimated as being salt-affected (FAO 2016). Globally, 3% of the world's soil resources are salt-affected in some way (FAO 2011). FAO (2002) estimated that salinity results in a reduction of 1–2% per year of global farmland. Others have estimated up to 50% of arable land could become salinity affected by 2050 (Wang et al. 2003; Thomas 2011; Butcher et al. 2016).

FAO (FAO/AGL 2000), reported that > 6% of the terrestrial biosphere has been salt-affected. A total of 434 million ha were estimated to suffer from sodicity problems, with 397 million ha impacted by salinity. In India, salinity and sodicity problems have been estimated as affecting 6.75 million ha (Mandal et al. 2010), with waterlogging affecting another 6.41 million ha (Maji et al. 2010). When considering land that is irrigated, an estimated 1/3 of the world's irrigated area is at risk of waterlogging, mainly where groundwater is shallow – and 20% of irrigated area is salt-affected (Ghassemi et al. 1995). This observation backs that made by FAO (2016). As such, some 75+ million ha of land has been exposed to varying forms of human-induced salinization (Bridges and Oldeman 1999; FAO/AGL 2000).

In Central Asia and the Caucasus, saline and sodic soils are common problems. In Central Asia, between 40% and 80% of irrigated lands were judged as being waterlogged and/or affected by salinity (FAO 2015b). In Russia, 54 million ha (equivalent to approximately 3.3% of the total national land area) is affected by salinity. In Ukraine, about 4 million ha (6.6% of the national territory) have also been reported as being affected (Novikova 2009). Moving south and across the Black Sea, salt-affected arable lands in Turkey have been estimated as being 60% slightly saline, 19.6% saline, 0.4% alkali and 8% saline-alkali, respectively (Senol and Bayramin 2013). This is not all a consequence of human activities. Naturally high level of salinity are common; only about 30% appear to have been caused by poorly managed irrigation. In Kazakhstan, saline soils (including Solonetz, alkaline soils, and other soil complexes) is approximately 41% of the national territory (Borovskii 1982). Much of this area is however naturally saline due to marine sedimentation in the country's geological history. Uzbekistan also suffers greatly from salinity problems, with 46.5% of the country's territory salt-affected in some way (Kuziev and Sektimenko 2009). Crucially, groundwater tables tend to <2 m below the soil surface on approximately one-third of Uzbekistan's irrigated land area. This results in a situation in which some 50% of irrigated lands suffer from excessive salinity levels (FAO 1985, 2015a). Salt-affected soils are also common in Turkmenistan. Roughly 29% of Turkmenistan's land area is subject to salinity (Pankova 1992) and are concentrated in the west close to the Caspian Sea. Up to 68% of the total area of irrigated soils in Turkmenistan is affected by excessive salinity (FAO 2015a). In Azerbaijan, 5.9% of national territory and 45% of irrigated lands are under salinity (Ismyilov 2013).

2.6.2 Acidic Soils

Soil acidity is measured by the concentration of hydrogen ions (H^+) in the soil solution on a logarithmic pH scale. This scale ranges from 1 to 14, while 7.0 being neutral. Points above and below, respectively, are acidic or alkaline (Reece et al. 2011; Raven et al. 2014; Acids and bases 2015). The quantification of the pH in a given soil is imperative for determining the availability of nutrients to plants, and also in selecting crops and crop management practices that are appropriate given a soil's acidity level. There have been a number of assessments of the extent of acid soils globally. Acid soils occupy 11% of the earth's terrestrial surface and it is one of the major consequences for sustainable crop production (van Wambeke 1976; Rao et al. 1993; Brusseau et al. 2019). Haug (1983) assessed that 30–40% of the arable soils in the world are acidic and about 70% of potentially arable land was also estimated to be acidic. This observation, however, requires refinement given the accelerated rate of urbanization and land-use change over the past four decades. Von Uexkull and Mutert (1995) conversely indicated that acidic soils cover ~30% global ice-free land area. Roughly 16.7% of these soils are found in Africa, with 6.1% in Oceania, 9.9% in Europe, 26.4% in Asia, and nearly 401% in the Americas. Eswaran et al. (1997b) suggested that some 26% of agricultural lands are crop production constrained because of soil acidity. At least 48 developing countries in the world are facing the problem of soil acidity, primarily in the tropics on Ultisols, Oxisols and Oxisols (Narro et al. 2001). Eighty-five percent of tropical South America has some level of soil acidity (Fageria and Baligar 2001).

Acid soils are distributed across northern and southern global belts. The northern belt is characterized by a relatively cold and humid temperate climate. The southern belt is conversely tropical with warm and humid conditions and higher rates of rainfall that affect the formation of acid soils (von Uexkull and Mutert 1995). Acid soils are most common in forest ecosystems (66% of the global forested area). Eighteen percent can conversely be found in grassland, savanna, prairie, and steppe vegetation based ecosystems. Acid soils cover quite large areas of potentially arable land. Estimates are however that just over 5% of the world's severely acid soils are cropped in some way (von Uexkull and Mutert 1995). The Los Cerrados Savanna of Brazil is a good area of land – about 205 million ha – which just over 112 million ha are potentially arable if acidity problems were to be ameliorated. The countries of Colombia, Venezuela, Central Africa, and tracts of coastal and mainland South and Southeast Asia have similarly potentially arable land resources (Hede et al. 2001).

2.6.3 Heavy Metals Affected Soils

Although insufficiently considered in research and agricultural development, soil heavy metal contamination is a significant problem (Kong 2014). Peralta-Videa et al. (2009) described the impact of soil-borne heavy metal contamination on food and human health, including mechanisms of retrieval, uptake, translocation and accumulation in plant tissues. Because of exposure to heavy metals, the risk of bio-accumulation and contamination in the food chain are an important concern (Begonia 1998; Franzaring et al. 2006; Divan Jr. et al. 2008). Determination of heavy metal threshold values – for both plants and animals including– is important in mitigation of risks. Setting sound risk thresholds for heavy metal contamination of crop organs are crucial; threshold level determination for different soil types are also important (Hamon and McLaughlin 2003). Most internationally accepted thresholds and guidelines to regulate and ameliorate heavy metal concentrations in agricultural soils are related to the use of biosolids from sewage sludge for waste disposal and fertilization, in addition to industrial contaminants (McLaughlin et al. 2000; Trofimova et al. 2012; Table 2.4). Considering human consumption of plant-based foods, the expected safe and adequate daily intake of zinc (Zn), iron (Fe) and copper (Cu) is between 10,000 and 20,000, 1000 and 12,000 μg day^{-1} (Annan et al. 2010). Levels are 11,000 μg day^{-1} for manganese (Mn) (Dey et al. 2009). The maximum allowable concentration of heavy metals in foods is 1 μg/g for cadmium (Cd) (Linder 1991; Annan et al. 2010), 100 μg day^{-1} for nickel (Ni) (Das and Dasgupta 2002), and 6, 25, and 75 μg day^{-1} for lead (Pb) in children, pregnant women and adults (Dharmananda 2012).

Table 2.4 The maximum concentrations of heavy metals recognized by various countries for agricultural soils receiving anthropogenic inputs of metals

Country	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
Australia	1	100	150	200
Australia	3	200	200	250
New Zealand	3	140	300	300
Europe (limits vary among state)	1–3	50–140	50–300	150–300
Vietnam, pH 6 (limits vary with pH)	2	120	70	200
USA	20	750	150	1400

Source: McLaughlin et al. (2000) and Trofimova et al. (2012)
Pb lead, *Zn* zinc, *Cd* cadmium, *Cu* copper

Heavy metals are capable of binding to plant cellular components including enzymes, proteins and nucleic acid. Even relatively low levels of contamination can interfere with the functioning of these components (Landis et al. 2000). Symptoms of heavy metal toxicity in plants vary depending on the type of metal or metal compound contamination, dose, and phenological stage during which contaminants are taken up from soil. Long-term exposure to excessive amounts of heavy metals beyond recommended threshold levels have been linked to the negative nervous system and circulatory system effects, in addition to cancer. Exposure to "classical toxic heavy metals" (cf. Nielen and Marvin 2008), chromium or the metalloid arsenic have been reviewed thoroughly by Afal and Wiener (2014).

Countries in South and Southeast Asia, as well as China, are recognized as facing considerable heavy metal soil contamination problems (Herawati et al. 2000; Luo and Teng 2006; Brus et al. 2009). Roughly 20 million ha of arable soils is estimated to have the high levels of contamination by heavy metals in China, as a result crop productivity is suffered (Wei and Chen 2001); for example, Wei and Chen (2001) estimated a potential reduction of > 10 million tons of food year^{-1} in China as a result of metal contamination of soils. Arsenic contamination in Bangladesh and Eastern India is widely recognized as a problem. As in soils, groundwater used for irrigation is also contaminated with naturally occurring As (Brammer and Ravenscroft 2009). Ahmed et al. (2011a, b) conducted a thorough mapping and statistical analysis of groundwater irrigation and As contamination in Bangladesh, and suggested that by 2020, 75% of the soils cropped to rice would have As contamination of at least 30 mg/L. This has important implications for consumers. Ahmed et al. (2016) conducted the most comprehensive analysis of human consumption of As in food in Bangladesh. They found that among rural and urban populations, 25.2% and 25.3% of the As consumed came from vegetables, respectively. Cereal consumption – primarily rice – however contributed 59.4% and 53.0% to daily As intake. For these reasons, a variety of irrigation strategies, varietal options and agronomic methods that can be used to mitigate As contamination risk have been proposed for Bangladesh (Ahmed et al. 2011a, b; Wichelns 2016).

2.6.4 Drylands and Drought-Affected Lands

Well over 1/3 of the world's population are affected by several forms of water-scarcity for at least one of the 12 calendar months of the year (WWF 2016). Within the next decade, an estimated 60% or more of the world population will also begin to experience serious water shortages, with negative consequences for agricultural productivity and human health. In Africa's humid to arid and semi-arid zones, both rain and wind erosion are the primary mechanical drivers of soil loss as soil and water erosion are estimated to affect 80% of Africa's soils, a situation that may be exacerbated by climate change (Desanker et al. 2001). Land degradation severity is to the greatest extent in Africa. The effects of degradation processes depend on soil taxonomy, agroecological and climatic conditions, and the footstep of intensification and type of agricultural and livestock activities predominant in particular areas. For example, the amount of SOM lost from soils in Burnina Faso's more humid and sub-humid southern environments with more precipitation are actually estimated at 16–50% greater than arid areas (Mando 2000). In addition to that, the Sahelian region is also facing increasing concerns of land degradation in the basin of Congo and Zambezi river and associated with water sheds, in addition to renewed concerns in the Nile and Lake Chad basins (Warren et al. 2003; Descroix et al. 2009). The United Nations Children's Fund, which tracks the countries and populations most affected by drought (Agrella 2015), estimated that approximately eight million people within Ethiopia – one eighth of whom are young children are at risk of recurrent drought and precipitation failures. Drought in the horn of Africa is exacerbated by conflicts and resulted in interruptions to food production, distribution and markets that nearly 1.3 million people are at risk of food insecurity also noticed by Agrella (2015) and OCHA (2016). Another three million people in Somalia are in similar risk (UNNC 2015). These issues extend further to the south. More than a half-million people in Uganda have been estimated as facing food shortages from drought, with herders particularly hard hit in the Karamoja and Teso in the north-east to the central region (UNISDR-AF 2015).

It is important to note that while drought itself is a problem, the consequences of drought are most commonly exacerbated by socio-political conflicts that drastically exacerbate impact – especially for the poor (Downs et al. 1991; Kebbede and Jacob 1988; Köpe 2019). Although famines and drought have been widely studied in Africa, Latin America and South Asia, a contemporary example is provided by Afghanistan. As a result of drought and conflict, more than 60% of the livestock found within Afghanistan are estimated to have died. More than 10% of the human population of Afghanistan also require emergency assistance (Agrella 2015). In the Middle East, Iran drought and international sanctions have rendered large portions of the population also at risk. In central Russia, however drought is an occasional problem. The Indian sub-Continent, Mongolia and China also experience occasional droughts that can interrupt agricultural productivity. The north-western Gansu Province of china has also experienced frequent reoccurring droughts that have led to emergency response plans and actions (Agrella 2015).

2.6.5 Lands Affected by Soil Erosion and Sedimentation

2.6.5.1 Soil Erosion

The soil erosion is often confounded with the broader soil degradation term. Erosion, however, refers specifically to direct physical loss of movement of soil and associated nutrients (Bhatt et al. 2016a, b). It is also a natural process that can be worsened through land use and management practices (FAO 2019). Generally, soil erosion occurs when soil particles are separated and moved from their original position through the mechanical action of wind, water, or ice movement. Particles are later deposited in new locations. The degree of erosion depends on the time-frame in which it is measured, as well as on a suite of general variables including soil physical properties, vegetative cover, gradient and slope, in addition to precipitation amount and intensity (Selby 1993; Euronews Reports 2015). Changes in land use and management systems directly affect erosion potential and speed (Ursic and Dend 1965; Wolman 1967; Hooke 2000). Where land-use managers, which include farmers and herders, do not make efforts to replace or replenish soil as it is used, erosive processes can be particularly severe and result in accelerated erosion (Lowdermilk 1953; Shaler 1905; Pimentel et al. 1987).

The impacts of erosion can be considerable. In the United States, estimates are that the total annual cost from erosion in terms of lost annual productivity is some US\$44 billion year^{-1}, which equates to US\$247 ha^{-1} of cropland and pasture on erosion affected lands (Eswaran et al. 2001). On a global and annual basis, Eswaran et al. (2001) suggested that 75 billion tons of soil are subject to erosion processes yearly, resulting in approximate foregone productivity losses of about US\$400 billion per year. In Central Asia, the total area affected by water erosion has been estimated to be approximately 30 million ha. Wind erosion is thought to affect some 67 million ha. More than 35% of the agricultural soils in the Caucasus are thought to be eroded, while in Uzbekistan and Tajikistan up to 80% and 60% of agricultural land is eroded in some way (CACILM 2006). In Russia, 26% of the agricultural land area is affected by medium to strong levels of water erosion (Ministry of Natural Resources 2006). In Ukraine and Maldova, one-third of the lands used for agriculture and livestock production are subjected to water and wind erosion (Leah 2012). One-tenth of Belarus and 79% of Turkey, respectively, are affected by erosion. Erosion is particularly severe on slopes >15°, for example in Turkey water and wind erosion are problems on about 500,000 ha (Senor and Bayramin 2013).

2.6.5.2 Soil Sedimentation

Following erosion, sedimentation is the deposition of detached soil particles in new territorial, aquatic or oceanic ecosystems. While sedimentation can serve to enrich the land and aquatic ecosystems where nutrients and SOM are redeposited, sedimentation can also reduce light penetration in water which can reduce primary productivity in aquatic systems. The resulting turbidity can thereby affect the population dynamic of aquatic organisms, many of which are important from an ecosystem services provision perspective. Sedimentation can also affect the transportation and deposition of pollutants, heavy metals, pesticide residues, and other undesirable contaminants (Beasley 1972). Although sedimentation from erosion is a concern, Syvitski et al. (2005) indicated that human activity has also reduced overall sediment delivery loads to oceanic systems due to stream and river obstructions and diversions. In addition, soil eroded from hill-slopes and other areas can be redeposited in colluvial or floodplains; when these areas are used for productive purposes, remobilized soil can actually benefit agricultural productivity (Costa 1975; Trimble and Crosson 2000). The causes and consequences of erosion and sedimentation should, therefore, be carefully considered in tandem, as not all erosion processes may be harmful when taken in a broader systems perspective.

2.7 Nutrient and Agrochemical Pollution

Agricultural pollution is the excessive accumulation of undesirable biotic and abiotic byproducts of crop and livestock production practices. Pollutants can compromise ecosystem functioning and result in adverse human and animal health consequences. Pollutants can be concentrated or diffuse in origin and may result in location-specific landscape-level pollution. Agricultural management practices play a crucial role in mitigating the production, distribution and impact of pollutants (Carl 2016). Farmers and livestock managers apply pesticides to control pests of crops and forage. When these pesticides accumulate and persist in soils, pollution can occur. Depending on environmental and specific toxicity factors, as well as the molecular composition of pesticides, the build-up of certain pesticides can affect soil microbial processes, cause toxicity to soil organisms, and can result in uptake and contamination of crops. When consumed by humans and animals, some pesticides can bioaccumulate and cause long-term or immediate health consequences. The persistence of pesticides in soils is a function of the compound's chemistry and ability to absorb the soil particles, which in turn affect the transport and fate of pesticides in environment (US-EPA 2006). In addition, pollutants can harm beneficial insects including ground and soil-dwelling natural competitors of crop pests (Gullan and Cranston 2010).

The mixing of pesticide molecules with water and vertical movement down and through soil layers is called leaching. When leached molecules come into contact with groundwater, they can contaminate it. Leaching rates depend on soil characteristics, the molecular characteristics and sorption qualities of pesticide active ingredients, and the rate of rainfall and/or irrigation (Andrade and Stigter 2009; Agrawal et al. 2010). The most rapid leaching can be expected in the case of water-soluble pesticides that are used in coarser textured soils, and when rainfall or irrigation occurs soon after chemical application and prior to the time at which molecules might bind to soil particles. Most leaching results from fields that have been treated with insecticides or herbicides, but locations where farmers mix, prepare and dispose of chemicals are subject to the same processes (Nicol and Kennedy 2008; Weisskop et al. 2013).

Application of N and P through synthetic fertilizers, manure, biosolids, or compost are crucial for crop and forage productivity. However, only a limited portion of nutrients applied are taken up by crop or forage species; the remainder can be converted to GHGs (particularly for N) or may accrue in the soil or be lost as runoff or leached. The additional N and P can have negative environmental and human health penalties, with significant insinuations for ecosystem functioning and the provision of ecosystem services (Heckrath et al. 1995; Carpenter et al. 1998). Where N is supplied in excess of the amount that can be used by a crop, there is a risk of groundwater contamination, especially in soils with low SOM or that are coarser in texture, and where rainfall or irrigation rates are high (Kirchmann et al. 2002). Very soluble nitrate fertilizers and unprocessed manures or sewage waste are particular concerns as they can result in transformation into nitrate and rapid leaching (Heckrath et al. 1995; US-EPA 2006), into groundwater where they can represent a concern for human health (Ju et al. 2007; Guo et al. 2010). The additional P can be leached in cases of over-application, the eutrophication can occur downstream due to surplus of nutrient stock, leading to anoxic areas called dead-zones (Heckrath et al. 1995; Carpenter et al. 1998; US-EPA 2006).

2.8 Causes of Soil Degradation

Land degradation comprises water and wind erosion, chemical degradation such as soil acidity and salinity, nutrients leaching, etc. and whereas physical soil degradation comprises crusting, compaction, hard-setting, etc. (Eswaran et al. 2001). For the first time, global assessment of soil degradation (GLASOD) project has developed a map for the severity of land degradation across the globe; they identified four major causes of land degradation such as deforestation due to the elimination of natural vegetation, overexploitation of vegetation for domestic purpose, overgrazing, and intensive agricultural practices (Olderman et al. 1991; FAO 1990). Egypt, Ghana, Central African Republic, Pakistan, Tajikistan, and Paraguay have all already experienced significant land degradation and soaring food prices as a result of land degradation (Braimoh 2015). UNO (2012) reported that due to land degradation we lose an area, approximately as the size of Honduras due to the desertification and also lose 24 billion tons of fertile soil due to erosion every year. It is threatening the livelihoods of 1.5 billion people and will likely to increase by 135 million by 2045. There have already been the first mass migrations in the Middle East, where the refugee crisis has been linked to years of drought in Syria and Iraq (UNO 2012).

2.8.1 Soil Erosion

As a cause of land degradation, soil erosion is a naturally occurring process, where soils' particles are displaced or transported to a new location. Water and wind contribute most to erosion under natural circumstances, but the movement of ice can also be important. Soil erosion is also accelerated with human intervention; soil loss from agricultural areas has been estimated to be 10–40 times greater than the natural rate of soil formation (Pimentel and Burgess 2013). Erosion may occur when soil is exposed to raindrop or wind energy. In New York State, researchers estimated that rainfall intercepted by soil is equivalent in energy 60,000 kcal (250×10^6 joules) year^{-1} given a quantity of 1000 mm of rainfall (Troeh et al. 1999). Even relatively small slopes of 2% can result in soil particle detachment and downhill movement. The sheet erosion is the most common type of rainfall-induced erosion that results in overland flow of soil, as it is common erosion in agricultural locations (Oldeman 1998; Troeh et al. 2004).

2.8.2 Soil Salinity

Due to the global climate change of salt-induced land degradation in well-thought-out to be the largest environmental problem in current times. Mostly in arid and semi-arid climatic conditions of Mediterranean region, salt-water irrigation induced land degradation is a common problem due to the scarcity of rainfall to preserve regularly the percolated water as well as a lack of improved drainage system; this prompts to gather the salts in the rhizosphere of the field crops, which ultimately damages the soil properties and finally affects the crop yield (Ali et al. 2001).

About 20% of the irrigated area in 75 countries across the globe is occupied within the sovereign borders of salt-affected soils and this percentage has increased over time (Ghassemi et al. 1995; Metternicht and Zinck 2003). For example, salt-induced land degradation is the common problem in the Indo-Gangetic Basin of India, the Indus Basin of Pakistan, the Aral Sea Basin of Central Asia, the Yellow River Basin in China, the Murray Darling Basin in Australia, the Euphrates Basin in Syria and Iraq, and the San Joaquin Valley in the United States (Ali et al. 2001; Metternicht and Zinck 2003). However, it has been documented that a huge part of salt-affected irrigated areas generally occurs where smallholder farmers fully depend on agriculture (Zekri et al. 2010).

2.8.3 Soil Acidity

Some soils are naturally acidic. Where this is the case, acidity results from the presence of weathered soil parent materials. Acid soils – particularly those with pH below 4.5 – are compromised in terms of agricultural productivity because many plant nutrients become unavailable at low pH levels. In addition, Al and some micronutrients become more soluble. When taken up in excessive quantities, they can induce toxicity and yield decline. These issues are a serious problem in high-rainfall tropical regions with highly weathered soils (Harter 2007). Considering potential anthropomorphic drivers of acidification, N addition can influence acidification processes within a soil. It is easiest to think these processes from a soil ecosystem perspective. N that enters or departs from the soil ecosystem as fertilizer or through gaseous losses, binding with organic matter, or through plant uptake does not generally contribute to acidification. Ammonium-based N fertilizers are major contributors to soil acidification when N leached in high rainfall environments or with irrigation, or where soil texture is coarse or soils are poor in SOM. Gazey and

Azam (2017) reported that the ammonium-based fertilizers are converted to nitrate and hydrogen ions as they are processed by soil microbiota. Depending on the amount and characteristics (N concentration) of fertilizer applied, this results in the build-up of H in the soil. As such, H ion cannot contribute to soil acidity. However, because only a portion of fertilizer applied to the crop is retrieved and taken up, remaining negatively charged ions do not bind with H and may contribute to acidification processes (Van Breemen et al. 1983; Gazey and Azam 2017).

Soils particles typically carry a negative charge. Particle surfaces attract and hold cations with positive charges including calcium, manganese, potassium, sodium, etc. Soil particles also hold H ions more strongly than these other ions, with only a few notable exceptions to this rule (Harter 2007). As such, when H ions in soil increase, they will typically displace base ions. These base ions then become subject to leaching risks that in turn affect acidification processes. In humid environments, well-drained soils can lose their base ions, resulting in soil fertility loss. As this process proceeds, H^{+} concentration on the surface becomes high so that Al^{3+}, Si^{4+}, and Fe^{3+} when released can cause toxicity problems (Harter 2007) of aluminium and iron, along with Kaolinite, become the dominant solids in the soil. As Al ion concentration increases and contaminates the soil solution, it can contend with other cations for interchange sites on soil particles. Base nutrients, therefore, increase in their risk of binding as they are no longer attached to negative receptor sites. These weathering processes are one of the key reasons why tropical soils in humid environments suffer soil fertility problems (Joint FAO/IAEA 2000). Acidification processes may also render P less available for uptake. Large portions of South America, Eastern Africa and mainland South East Asia for example associated with acidic and P fixing soils. This occurs as Al and Fe are released over time and become accessible in solution or exchange sites. Both ions interact with phosphate and can be fixed through the formation of difficult to solubilize compounds (Joint FAO/IAEA 2000).

2.8.4 Soil Structural Decline

Soil structure may be defined as the ways in which the constituent particles of sand, silt, and clay are assembled into larger particulate aggregates (Marshall and Holmes 1988; Gardner et al. 1999). Aggregation processes will differ depending on soil textural composition, organic matter, and the degree of mechanical disturbance, resulting in different soil structures. To be more precise, soil structure may be influenced by oxides, hydroxides, carbonates and silicates. It is also heavily influenced by fungal activity, biofilms, and proteins within the soil. Cation exchange capacity is both a consequence and cause of soil structural composition, influencing both clay minerals and organic compounds (Dexter 1988; Daly et al. 2015; Masoom et al. 2016). Soils structure, in turn, affects the movement and availability of water within a given soil (Dexter 1988). Soil structure, however, can be disrupted where land use and farm managers insufficiently supply SOM or maintain SOM and soil biological activity (Daly et al. 2015). Repetitive tillage may also reduce soil structural quality and cause break-down of aggregates. Mechanical mixing of soil through tillage and weeding practices can also compact soils and fill pore spaces that make water conservation and moisture retention challenges. Tillage and mechanical disturbance of soils will also result in oxidation of SOM that can accelerate structural decline (Young and Young 2001).

2.8.5 Degradation Due to Lack of Soil Cover

Soils that are protected by plant biomass – either living or dead – will be generally less subject to erosion processes due to physical wind destruction and dissipation of raindrop energy on biomass rather than the soil surface (Pimentel 2006; Zia-ur-Rehman et al. 2016). The loss of vegetative soil cover is however prevalent in industrialized farming systems and in developing nations where agricultural intensity is increasing without sufficient policy attention to inspire the use of more viable management practices. In a number of developing nations, stallholder farmers and rural households may also commonly rely on dead crop residues for cooking, heating and roofing material, in addition to as a fodder source for livestock (Uddin and Fatema 2016; Uddin and Goswami 2016). In the 1990s, about 60% and 90% of the residues produced by farmers in China and Bangladesh, respectively, were routinely removed from fields as fuel or fodder (Owen and Jayasuriya 1989; Uddin and Fatema 2016; Uddin and Goswami 2016). In areas where fuelwood and other biomass are scarce, the roots of grasses and shrubs may also be collected and burned as a fuel source (McLaughlin 1991). Increase in cropping intensities, inadequate use of cover crops mulches, and use of short statured cereal varieties (Kaspar and Singer 2011) can leave soils unprotected and hence subject to erosion.

2.8.6 Topographical Effects on Land Degradation

In addition to the fluctuation in land-use practices and deforestation, the topography and slope of a given landscape exert an influence on erosion and land degradation processes (Lal and Stewart 1990). However, even smaller slopes can result in erosion given topographical positioning and exposure to the elements. In the Philippines, 58% of land area has a slope >11°, and in Jamaica 52% has a slope of 20°. Soil erosion rates at both locations reaching up to 400 tons of loss ha^{-1} $year^{-1}$ have been reported (Lal and Stewart 1990). In arid environments with relatively strong and intensive winds, soil loss at 5600 t ha^{-1} $year^{-1}$ has been reported in India (Rao et al. 2016). In the United States, however, where erosion control practices are now widely applied due to supportive policy, erosion on slopes has been limited to an average of 13 tons ha^{-1} $year^{-1}$ (Nearing et al. 2017). Soil loss from sloped agricultural lands in Europe is estimated to range from 3 to 40 tons ha^{-1} $year^{-1}$, though severe storms and extreme weather events have resulted in losses nearly 2.5–5 times higher (Grimm et al. 2003; Verheijen et al. 2009).

2.8.7 Adverse Effects of Land Degradation on Crop Productivity

Land degradation is likely to endure as a vital global issue for the twenty-first century due to its hostile impacts on land, environment, and on the food security of increasing population. Land degradation is also an important issue in terms of the Sustainable Development Goals (SGDs), including SGDs number 1 (no poverty), 2 (zero hunger), 3 (clean water and sanitation), 13 (climate action), 14 (life below water) and 15 (life on land). Considering the agricultural productivity, which provides support for a number of these goals, the impacts of land degradation can be differentiated into on- and off-site. Loss of land and soil quality on-site where degradation occurs (e.g. physical erosion) can compromise ecosystem services and the ability of farmers and livestock managers to produce food and animal products. Off-site effects can be positive (where sediments are deposited and increase soil quality) or negative (through pollution, sedimentation, and other processes discussed in this paper). Despite increasing land degradation problems, farmers have been able to 'mask' the on-site impacts of land degradation through the use of additional inputs (e.g., increasing fertilizer rate) and through the use of less damaging agricultural technologies (e.g., zero-tillage land preparation and crop establishment systems). However, the longer-term consequences of degradation both on- and off-site required continued and focused attention if this slow yet crucial problem is to be arrested.

The relative magnitude of economic losses from management and land-use changes in comparison to natural ecological worsening processes also has created some debate. Some economists have argued that the on-site impact of soil erosion related land degradation processes may not be severe enough to warrant corrective national or international polices (Eswaran et al. 2001; Sivakumar and Stefanski 2007). They, in turn, argue that land managers should be solely responsible for stewarding their land resources and maintaining land productivity in the long-term. Agronomists and soil scientists have conversely pointed out that soil formation processes are extremely slow, and that soil is in many ways a non-renewable resource (Fonte et al. 2012; Shaxson et al. 2014a, b). Given that some of the effects of land degradation may be irreversible at time-scales relevant to land managers and farmers, they argue that masking effect some of the technologies described above can provide a false sense of security (Eswaran et al. 2001).

The productivity of some lands may have declined by 50% or more due to soil erosion and desertification (FAO 1995; Irshad et al. 2007). Yield reduction in Africa due to past soil erosion may range from 2% to 40%, with a mean loss of 8.2% at a continental level (Eswaran et al. 2001; Sivakumar and Stefanski 2007). In South

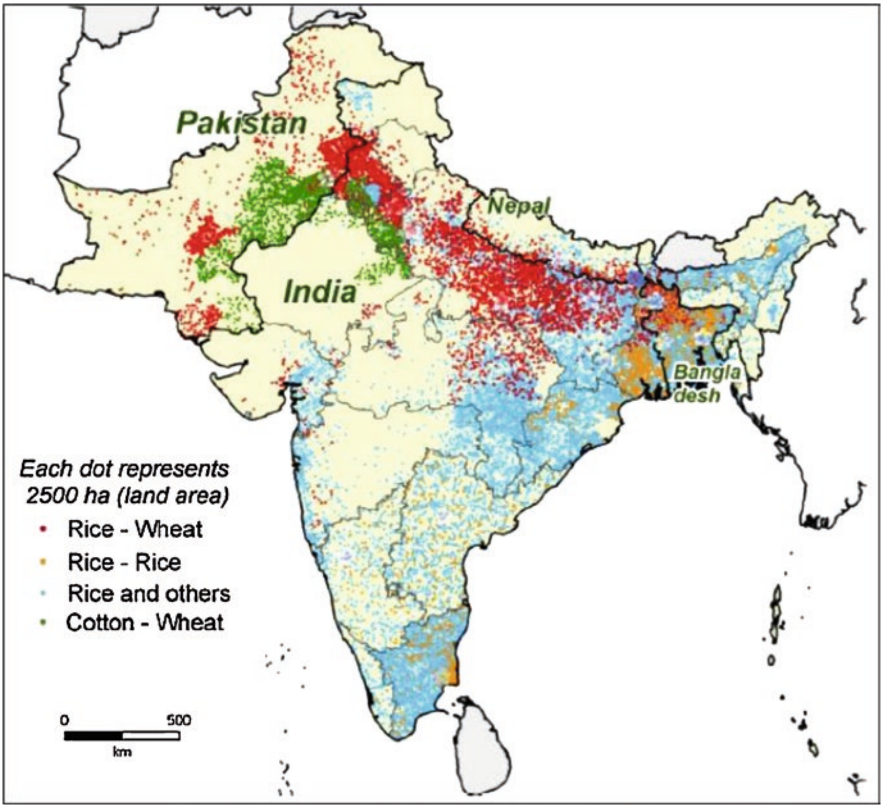

Fig. 2.1 The extent of major cereal-based cropping sequences in Pakistan, India, Nepal and Bangladesh. (Source: IRRI 2009)

Asia, where crop management practices are irresponsibly implemented in rice-wheat cropping sequences, declining soil health and unsustainable groundwater abstraction have been cited as concerns (IRRI 2009; Fig. 2.1). Further, the annual foregone loss in agricultural productivity for land degradation is estimated at 36 million tons of cereal equivalent, which has been valued at US$5400 million for water erosion, and US$1800 million for wind erosion (No¨sberger et al. 2001).

Only about 3% of the global land surface is likely to be prime or Class I land. This land is generally not found in the tropics. Another 8% of the land is in Classes II and III. Taken together, better quality land in Classes I-II are just 11% of available land resources that are needed to produce for the global population. Conversely, desertification processes are underway on an estimated 33% of the global land surface. This affects more than a sixth of the global population, half of whom live in Africa, where population densities are also on the rise (Eswaran et al. 2001).

An important problem with many land degradation estimates is the lack of a firm cause-effect relationship between severity of degradation and declining agricultural productivity. This is further complicated by the scale at which analysis takes place.

For example, erosion processes are certainly problematic for a particular farmer losing soil from his or her field. But when considered in a landscape context, lost soil from one field that is deposited on another could conversely improve fertility when SOM rich topsoil is remobilized. In addition, common criteria for differentiating different levels of land degradation (e.g. low, moderate, high) are generally based on land and soil physical properties. As it is a challenging task (Lal 1997), rarely are these effects measured in terms of the potential loss of productivity or ecosystem services provided by soils. Data from China provided by the International Board for Soil Research and Management (IBSRAM) demonstrates this challenge (Maglinao et al. 2003).

Despite the measurement of significant changes for the cumulative soil loss and water runoff, researchers found no alterations in the productivity of maize in different experimental treatments. In studies on upland rice in Thailand, soil loss ranged dramatically 330–1478 t ha^{-1} depending on agronomic practices (Maglinao and Santoso 2000; Maglinao et al. 2003). The corresponding yield of rice, however, ranged from 4.0 to 5.3 t ha^{-1}, with the lowest yield in treatments that had the least soil loss. These problems arise because crop yield is an integrative effect of numerous environmental, plant physiological and agronomic management factors. This has however not stopped researchers from approximating these relationships and extrapolating them. Such *ex ante* research is needed to understand the overarching risks associated with land degradation processes. Examples of early studies included based entirely on secondary data and estimated that global potential land productivity had been reduced between 15% and 30% lower as a result of soil erosion (IPCC 2019).

Other estimates are based on more empirical evidence. Dregne and Chou (1992) estimated that approximately one-third of irrigated land in Asia and more than half of the rainfed cropland in Asia and Africa had respectively experienced 8% and 10% loss of productive potential. Rangelands were however estimated to be much more severely impacted, with potential productivity losses often in excess of 50%. Using GLASOD data, Crosson (1997) estimated the distribution of the global agricultural supply disruption due to land degradation. In percentage terms, a 15%, 35% and 75% yield decline respectively for light, moderate, and strongly degraded cropland soil was estimated, while rangeland soils were estimated to have losses in the same categories of 5%, 18% and 50%, respectively. Oldeman (1998) subsequently used Crosson's datasets and loss coefficients, but estimated with modifications in his assumptions that croplands were 12.7% lower in potential productivity than pastures as a result of land degradation, resulting in a total foregone agricultural loss of 4.8%. These figures point to important implications for food production and consequent food access and security, especially in developing nations.

In sub-Saharan Africa, agricultural productivity and food security are at serious risk due to problems with the maintenance of soil fertility. This is especially the case for fragile soils in arid environments, and on sloping lands in the humid tropics. Despite these concerns, relatively little reliable data exist on the extent of degradation and implications for farm and rangeland productivity (FAO 1995; Warren et al.

2001). For these reasons, soil degradation in Africa and elsewhere has been defined as a "global pandemic" (DeLong et al. 2015).

2.9 Scope for Agricultural Land Expansion as a Response to Degradation

Several findings discussed previously revealed that to meet the food security of the growing population by 2050, agricultural productivity has to increase by 70–110% (Alexandratos and Bruinsma 2012; FAO 2015). A number of researchers (Gibbs et al. 2010, 2015; Lambin et al. 2013) have indicated that most of the best arable land across the globe have already been put into production. Eitelberg et al. (2015) reviewed land availability estimates and found a very limited potential for expansion due to competition for land from other uses. Expansion of agriculture into new lands is also associated with deforestation and the conversion of natural ecosystems, with important and often negative consequences for biodiversity that conflict with the above-mentioned SDGs (Eitelberg et al. 2015; Hailemariam et al. 2015). For these regions, several authors and organizations have underscored the need for improved and sustainable management of both soils and land today and in the future (Bruinsma 2011; Alexandratos and Bruinsma 2012; Mauser et al. 2015; FAO 2015).

The land surface of the earth totals approximately 13.0 billion ha. Of this and, estimated 1.5 billion ha lands are unmanaged and considered to be 'wasteland' from an agricultural productivity perspective. Another 2.8 billion ha are unused but also generally inaccessible to farmers and would require appropriate land clearing and conversion practices to be cropped (Oldeman 1994; Utuk and Daniel 2015).

Recent estimates based on the trend and rate of land degradation have indicated that top-soils in key agricultural producing regions may be fully degraded in the next 60 years (World Economic Forum 2012). At least 40% of the soil used for agriculture globally is in some stage of degradation. Considering a global mean estimate, soils are being lost at 10–40 times the rate of which they can be replenished through natural processes (World Economic Forum 2012). As pointed out in this review, many developing nations have not been able to sufficiently implement policies protecting soils on-farm and rangelands from human-induced degradation. Although practices could be implemented to build soil quality and reduce degradation, agriculture is nevertheless often practiced on soils that can be described only as marginally suitable (Beek et al. 1980; World Economic Forum 2012). More concerning is that even marginally suitable soils are facing competition from other land uses, most notably rapid urbanization that is displacing farmers in a number of countries (Hillel 1991; Nizeyimana et al. 2001; Montgomery 2007). Continued urbanization without adequate land use planning and zoning are likely to be a continued threat to agricultural production in the future (Nizeyimana et al. 2001; Alexandratos and Bruinsma 2012; Smith et al. 2016).

The opening of new cropland has historically been made possible through relatively destructive environmental practices, including conversion of forests, grasslands and wetlands. Such conversion has high environmental, biodiversity and social impacts. As such, continued attention on land degradation remains important as it is an important threat to biodiversity and the environment, in addition to future food production (Bruinsma 2003; Montgomery 2007; Conway 2012; Lambin et al. 2013; Utuk and Daniel 2015). As finding alternative land resources for new agricultural production is unlikely given the extent of human management of farm and rangelands (Hanson 2015), methods that sustainably intensify crop and livestock productivity on current land, while lessening the environmental externalities and increasing the movement of ecosystem services in the production of agricultural crops are urgently needed (Tilman et al. 2001; Bruinsma 2003; Lambin and Meyfroidt 2011; Gelfand et al. 2013; Lambin et al. 2013; Garnett et al. 2013). In addition, land rehabilitation practices and methods to remediate soil pollution and arrest erosion through conservation practices will be crucial in meeting this objective (Gibbs and Salmon 2015).

2.10 Conclusion

Recent UN projections indicate that population will grow to 9.8 billion by 2050, with 70% of the earth's inhabitants expected to reside in urban areas. Considering increasing population and changing dietary habits in developing nations, annual production of cereals should be increased to about 3 billion tons (about 50% more) by 2050 from 2.1 billion today to keep pace with demand. Without changes in dietary patterns, demand for meat is expected to grow with increasing wealth and development in a number of nations. This in itself is an issue that requires attention as dietary practices must shift to reduce environmental pressure and degradation. Changing diets and preferences, however, is not a simple task, and given demand projects, annual global production of meat is anticipated to grow from 200 million to 470 million tons. In response to these patterns, intensive agricultural practices are increasing in many developing countries, although farmers' practices are often less than desirable from a sustainability standpoint. Today, more than 1/3 of available land globally and almost 1/2 of vegetated land is being used for food production. Conversion of forests to crop and pasture land are also a significant concern from the standpoint of land degradation and biodiversity loss. Some 35 million km^2 of the land area (24%) of the earth is estimated to have been degraded in some way by human activity. Considering these urgent issues, this review attempted to provide a relatively comprehensive outlook of the causes, types and consequences of land degradation, in order to position policy-makers and environmental and agricultural planners with actionable information. This chapter also provides a synopsis of agricultural land degradation issues while providing potential solutions to reverse soil quality decline through an understanding of integrated land management practices. In addition to providing a synopsis of the impacts of land degradation on agricultural land productivity, the review provides data and a broad background for specialists in the fields of agricultural development, soil science, geography, economics, and for environmental management.

Financial Support This is an international collaborative work. A portion of the time allocated by TJK has been covered by the USAID and BMGF supported Cereal Systems Initiative for South Asia (CSISA) project and the MAIZE CGIAR Research Program (MAIZE CRP). The results of this research do not necessarily reflect the views of USAID, the MAIZE CRP, the United States Government, or the BMGF.

Conflict of interest Authors declared no conflict of interest.

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Chapter 3
Promising Technologies for Cd-Contaminated Soils: Drawbacks and Possibilities

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Abstract Soil contamination caused by Cd (Cadmium) is a serious problem worldwide which is broadly distributed contaminant in the soil ecosystem. Refining plants, sewage sludge, manure application, mine tailings and use of phosphate fertilizer have led to an increase of Cd concentration in soil. Cd-contaminated soils are perceived as great threat to public health in many counties. This article critically reviewed the current state of phytoextraxtion applied for Cd contaminated soils and specifically discussed various enhancements factors for Cd phytoextraction considered as ecologically efficient approach for Cd clean up. This article presents an analysis mainly based on the results of different pot experiments and field trials aimed to remediate Cd-contaminated soils using different herbaceous and tree species for Cd contaminated soils in the recent years. The promising results of field experiments have laid the foundation for Cd phytoextraction into feasible application to cleanup moderate Cd contaminated soils in Asia and Europe, however this approach has not achieved ecological sustainability to execute on large-scale area

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_3

due to week adaptation in wild environmental conditions. The integrated approach that employs a combination of Cd hyperaccumulator plants, soil amendments, chelating agents and soil microorganism may be used to remediate Cd contaminated soils, with the aim of securing methods that are economically and technologically feasible.

Keywords Soil pollution · Cd · Phytoextraction · Microbes · Chelators · Remediation

3.1 Introduction

Cadmium (Cd) contamination is a growing threat to soil ecosystem which requires immediate attention. The natural occurrence of Cd in soil ecosystem should not be exceeded more than 1 mg/kg (Mahar et al. 2016). Chemically, Cd is a transition metal and possesses the same qualities like mercury and zinc. Hetherington et al. (2008) has reported that 23,00 tons of Cd produced around the world based on the findings of British Geological Survey. Cd is regularly recycled among air, water and soil by different sources (Mahar et al. 2015; Xiao et al. 2015). The anthropogenic sources i.e. smelting, mining, waste disposal, application of phosphate fertilizers and metal plating release higher content of Cd in soil (WHO 1992; McLaughlin et al. 1999). Cd is also extensively used in manufacturing of plastics, pigments, batteries, stabilizers, corrosion-resistant steel plating, and solar panels. Cd pollution in soil has been extensively studied in the past decades (Culbard et al. 1988; Simmons et al. 2005; Chlopecka, 1996; Pietz et al. 1978). Several studies have documented Cd level in polluted soils can be 1–4 times more than in unpolluted soils. Simmons et al. (2005) has reported that the highest Cd concentration in soil samples of paddy field around mineralized area of Zinc was upto 284 mg/kg, approximately 99% more than the safe limits of Cd level (0.15 mg/kg). Cd causes some deleterious human health impacts i.e. proteinuria, genetic stability, kidney stone formation, reduce filtration rate of glomerular and causes cancer of various types in human body (Goel et al. 2006; Mcmurray and Tainer 2003). Cd can significantly be transferred to human body through consumption of contaminated food grown on the polluted soils (Jennings 2005; McLaughlin et al. 1999).

Different studies have reported that increased Cd concentration in cereal foods grown on Cd polluted soils have always exceeded the safe limits for human health (Lee et al. 1999; Williams et al. 2009; Cunningham and Ow 1996). A survey conducted in different provinces of China has reported that 70 of all paddy fields in the areas of mine polluted soils did not meet the national safe limits of Cd for food crops (Demirezen and Aksoy 2006). The alarming Cd pollution has already led to increasing public concern and therefore, it needs sustainable cleanup approaches for Cd-contaminated soils.

The Cd-contaminated soils can be controlled through various ways i.e. soil incarnation, landfill, vitrification, soil washing, electroreclamation and leaching. These cleanup technologies are expensive and disruptive to terrestrial ecosystem. Phytoextraction is an emerging technology that uses plants to remediate Cd contaminated soils and received increasing attention since couple of decades. It is environmentally sustainable, efficient and potential low cast (Watanabe et al. 1996). The aim of this review article to present critical analysis on current state of phytoextraction technology applied to remove Cd from contaminated soils and discusses various enhancement strategies to improve Cd remediation in contaminated agricultural soils. The phytoextraction is a widely recognized approach for Cd remediation among other phytoremediation options.

3.2 Phytoextraction

3.2.1 Natural Cd Phytoextraction

Phytoextraction technology uses several hyperaccumulator plants to remove metals in contaminated soils (Tang et al. 2003). The use of biotechnological applications for enhancing the removal capacity of potential hyperaccumulators and for root exudation of natural chelators are vital approaches to reduce the recurring expenses of soil remediation (Schmidt 2003). As root surface area exposed to soil demonstrate a critical role in phytoaccumulation of heavy metals so the plant selection for soil remediation is a significant step (Prasad and Freitas 1999).

Prasad and Freitas (2002) and Chaney et al. (1997) have reported that natural phenotypes of metal accumulating plant species are effective in phytoextraction. Hyperaccumulators which belong to families i.e. Carophyllaceae, Betulaceae, Fabaceae, Brassicaceae, Poaceae, Plumbaginaceae, and Fagaceae are documented to tolerate metals. Most of hyperaccumulators belong to Brassicaceae. High biomass production and fast growth rate are recommended as critical plant features which must be considered while selection of a plant for phytoextraction (Pilon-Smits 2005; Prasad and Freitas 2002; Schmidt 2003; Prasad 2004).

Table 3.1 shows the several plant species identified as Cd hyperaccumulators. Most Cd hyperaccumulating plants have been reported in naturally occurring metal-rich soils i.e. *Arabidopsis halleri*, penny-cress (*Thlaspi praecox*), penny-cress (*Thlaspi rotundifolium* ssp. *Cepaeifolium*), Salsola kali, violet (*Viola baoshanensis*), *Sedum alfredii*etc. On the other hand, there are many new Cd hyperaccumulators which have been found in un-polluted soils i.e. *Rhamnus globosa (*Yang et al. 2004) and *Solanum nigrum* (Wu et al. 2010). The metallicolous ecotype species are more capable to accumulate Cd and have a more capacity of Cd uptake and accumulation, as compared to non-metallicolous ecotype species (Wei et al. 2006). In addition, the Cd hyperaccumulators are pseudometallophyte species exhibiting metallicolous (grown on Cd-contaminated soils) and nonmetallicolous populations (grown on non-contaminated soils), except *Viola baoshanensis*, which is endemic to a Pb/Zn mine site (Wei et al. 2005).

Table 3.1 List of Cd hyperaccumulators plant species for phytoextraction

Species	Family	Geographical Distribution	Hyperaccumulation	Cd accumulation (mg/kg)	Reference
Herbaceous species					
Amaranthus mangostanus L. (cv. *Tianxingmi*)	Amaranthaceae	China	Cd	260 (shoots)	Fan and Zhou, (2009)
Amaranthus hybridus	Amaranthaceae	Worldwide	Cd	242 (shoots)	Zhang et al. (2010)
Arabis gemmifera	Brassicaceae	Pb/Zn mining site	Cd/Zn	5600 (leaves) 6643 (stems)	Kubota and Takenaka, (2003)
Arabidopsis halleri	Brassicaceae	Central Europe, Eastern Asia	Cd/Zn	5722 (shoots) 281 (leaves)	Yang et al. (2002)
Arabis paniculata	Brassicaceae	Asia, temperate regions	Cd/Zn/Pb	1662 (leaves) 434 (shoots)	Tang et al. (2009)
Atriplex halimus subsp. *Schweinfurthii*	Chenopodiaceae	Algerian salt steppes	Cd	218 (shoots)	Nedjimi and Daoud, (2009)
Arthrocnemum macrostachyum	Chenopodiaceae	Worldwide	Cd	70 (shoots)	Redondo-Gomez et al. (2010)
Azolla pinnata	Azollaceae	Africa, Asia, Australia	Cd	740 (tissues)	Rai, (2008)
Bidens pilosa L.	Asteraceae	Worldwide	Cd	108–376 (stems), 144–400 (leaves), 27.9–101 (seeds)	Sun et al. (2009)
*Beta vulgaris*var. Cicla L.	Chenopodiaceae	China	Cd	>100 (leaves)	Li et al. 2007
Brassica napus L.*	Brassicaceae	Europe and Central Asia	Cd	11.94 (stems), 25.3 (leaves), 263 (leaves)	Rossi et al. (2002)
Carthamustinctorius L.	Asteraceae	Semi-arid region of the temperate climates in many parts of the world	Cd	149–277 (leaves)	Sayyad et al. (2010)
Chara aculealata	Characeae	Worldwide	Cd/Pb/Zn	1544 (thalli)	Sooksawat et al. (2013)
Chromolaena odorata	Asteraceae	Southeast Asia, India, Africa,Australia	Cd/Pb	102 (shoots)	Tanhan et al. (2007)

Species	Family	Geographical Distribution	Hyperaccumulation	Cd accumulation (mg/kg)	Reference
*Crassocephalum crepidioides**	Asteraceae	Tropical Africa	Cd	121 (shoots)	Yamato et al. (2008)
Eleocharis acicularis	Cyperaceae	Asia	Cu/Zn/As/Cd	239 (shoots)	Sakakibara et al. (2011)
Echinochloa polystachya	Poaceae	Tropical and subtropicalAmerica	Cd	233 (leaves)	Solís-Domínguez et al. (2007)
Glycine max (cv. Suzuyutaka)*	Fabaceae	East Asia	Cd	0.83 to 4.29 (shoots)	Murakami et al. (2007)
Gynura pseudochina (L.)	Asteraceae	Southeast Asia	Cd/Pb	457 (shoots)	Phaenark et al. (2009)
Helianthus tuberosus L.	Asteraceae	North America	Cd	>100 (stemsand leaves)	Chen et al. (2011)
*Iris lactea*var.chinensis	Iridaceae	Europe	Cd	529 (shoots)	Han et al. (2007)
*Lonicera japonica*Thunb.	Caprifoliaceae	Temperate and tropical Regions worldwide		345 (stems) 286 (shoots)	Liu et al. (2009)
Lycopersicon esculentum cv. Shenbaofen	Solanaceae	Worldwide	Cd	130 (shoots)	He et al. (2009)
Mirabilis jalapa L.	Nyctaginaceae	South America and China	Cd	146 (shoots), 136 (leaves)	Zhou et al. (2006)
Oryza sativa (cv. Milyang 23) *	Poaceae	Worldwide	Cd	0.225 (shoots), 0.160 (roots)	Murakami et al. (2007)
Oryza sativa (cv. Nipponbare) *	Poaceae	Worldwide	Cd	0.133 (shoots), 0.324 (roots)	Murakami et al. (2007)
Pennisetum purpureum	Poaceae	Eastern and Southern Africa	Cd	47 (shoots)	Zhang et al. (2010)
Phytolacca Americana	Phytolaccaceae	Worldwide, invasive	Cd/Mn	10,700 (leaves), 2840 (stems)	Peng et al. (2008)
Picris divaricate	Asteraceae	Asia-temperate	Cd/Zn	1109 (shoots)	Tang et al. (2009)
Potentilla griffithii	Rosaceae	Asia-temperate,Asia-tropical	Cd/Zn	1670 (leaves)	Wang et al. (2009)

(continued)

Table 3.1 (continued)

Species	Family	Geographical Distribution	Hyperaccumulation	Cd accumulation (mg/kg)	Reference
Prosopis laevigata	Fabaceae	Tropical and temperate regions	Cd/Cr	8176 (shoots)	Buendia-Gonzalez et al. (2010)
Rorippa globosa	Brassicaceae	Tropical and subtropical regions	Cd	150 (leaves)	Wei et al. (2006)
Salsola kali	Chenopodiaceae	Russia, Mongolia, and China	Cd	2075 (stems), 2016 (leaves)	de la Rosa et al. (2004)
Sedum alfredii	Crassulaceae	Asia-temperate, Eastern Asia	Cd/Zn	9000 (leaves)	Yang et al. (2004)
Siegesbeckia orientalis L.	Asteraceae	Tropical, subtropical, and temperate zones	Cd	117 (shoots), 193 (shoots) 77 (shoots)	Zhang et al. (2013)
*Solanum nigrum*L.	Solanaceae	Tropical and temperate regions	Cd	125 (leaves) 310 (leaves)	Sun et al. (2007)
Solanum photeinocarpum	Solanaceae	Tropical and temperate regions	Cd	132 (stems), 158 (leaves) 215 (stems), 251 (leaves)	Zhang et al. (2011)
Tagetes patula	Asteraceae	Mexico and Nicaragua	Cd	126 (leaves) 108 (stems)	Sun et al. (2011)
Thlaspi caerulescens	Brassicaceae	Europe	Cd/Zn/Ni	2120 (rosetter), 319 (shoots) 2800 (shoots), 6100 (shoots)	Wojcik et al. (2005)
Thlaspi praecox	Brassicaceae	Southern and eastern Europe	Cd/Zn	1351 (seed), 2700 (shoots), 5960 (shoots)	Liu et al. (2004)
Thlaspi rotundifolium ssp. *Cepaeifolium*	Brassicaceae	Mountainous areas of France, Italy, Central Europe, and Slowenia	Cd/Pb/Zn	108 (shoots)	
Viola boashanensis	Violaceae	Endemic to the Baoshan Pb/Zn mine area (China)	Cd	1168 (shoots), 4825 (shoots)	Liu et al. (2004)
*Zea mays**	Poaceae	Worldwide	Cd	242 (shoots)	Hernández-Allica et al. (2008)

Species	Family	Geographical Distribution	Hyperaccumulation	Cd accumulation (mg/kg)	Reference
Tree Species					
Salix alba (S-141 clone)	Salicaceae	Europe and western and central Asia	Cd	113 (leaves), 50 (twigs)	Vysloužilová et al. (2003)
Salix dasyclados	Salicaceae	Mountainous areas of Eurasia	Cd	60 (leaves), 47 (twigs)	Fuksová et al. (2009)
Salix smithiana (S-150 clone)	Salicaceae	Europe and central Asia	Cd	103 (leaves), 132 (roots)	Vysloužilová et al. (2003)
Populus Canadensis	Salicaceae	Northern Hemisphere	Cd	3 (leaves), 10 (roots)	Sell et al. (2005)
Populus nigra × *maximoviczii*	Salicaceae	Europe, southwest Asia, and northwest Africa	Cd	36 (Leaves)	Komárek et al. (2008)
Paulownia tomentosa	Paulowniaceae	Central and western China	Cd	9–18 (leaves)	Doumett et al. (2008)
Salix viminalis (78198 clone)	Salicaceae	Europe, Western Asia, and the Himalayas	Cd	8 (leaves), 7 (roots)	Sell et al. (2005)
Salix viminalis (Arresoe clone)	Salicaceae	Europe and Western Asia	Cd	18 (leaves)	Jensen et al. (2009)

aIndicates nonhyperaccumulator plant species

3.2.2 Chemically-Assisted Cd Phytoextraction

Many studies have documented the potential of chelating agents in Cd-phytoextraction in field trails. However, several ex situ studies have proven that this technique is not yet ready for large scale application. Similarly, in ex situ experiments, EDTA is the most extensively studied chelating agent in field experiments. However, less number of in situ studies have exploited the potential of biodegradable chelating agent like Ethylenediamine-*N*, *N′*-disuccinic acid (EDDS). This may be due to the reason that such chelants are very costly to be used in widespread application. Though, it is not evident from the literature that EDDS or citric acid is more potential than EDTA (Chen and Cutright 2001; Meers et al. 2005). The application of hot (90 °C) EDDS (5 mmol/kg) or EDTA (3 mmol/kg) is capable of improving the Cd extraction by *Phaseolus vulgaris* (Table 3.3; Luo et al. 2006). These studies have argued that these enhancements caused the root damage due to adding hot solutions in soil, which facilitate easy entry of Cd into root xylem (Table 3.2A). The applied dose 1.8 mmol/kg of HEDTA in contaminated soil has reduced the extraction of Cd due to toxic effect to *Helianthus annuus* (Table 3.2A; Sun et al. 2009).

Table 3.3 List of microorganisms capable of improving % Cd removal of plant species

Microorganism	Type of microorganism	Plant species	% Cd removal	Reference
A mixture of AMF	AMF	*Lolium multiflorum*	N.D.	Yu et al. (2005)
Bacillus sp. RJ16	Bacteria	*Brassica napus*	0.03	Sheng and Xia (2006)
Candida ernobii	Fungus	*Zea mays*	0.04	Usman and Mohamed (2009)
Glomus mosseae	AMF	*Zea mays*	0.12	Usman and Mohamed (2009)
Glomus intraradices PH5	AMF	*Nicotiana tabacum*	0.37	Janoušková et al. (2005)
Glomus intraradices BEG75	AMF	*Nicotiana tabacum*	1.0	Janoušková et al. (2005)
Glomus caledonium	AMF	*Elsholtzia splendens*	0.02	Wang et al. (2006)
Hebeloma crustuliniforme	Fungus	*Populus canadensis*	0.67	Sell et al. (2005)
Paxillus involutus	Fungus	*Populus canadensis*	0.9	Sell et al. (2005)
Pisolithus tinctorius	Fungus	*Populus canadensis*	0.63	Sell et al. (2005)
Pseudomonas sp. RJ10	Bacteria	*Lycopersicon esculentum*	0.29	He et al. (2009)
Trichoderma atroviride F6	Fungus	*Brassica juncea*	<0.21	Cao et al. (2008)

Table 3.2A Ex-*situ* experiments using herbaceous species and chelates to enhance phyto-extraction of Cd

Chelant	Dose (mmol/kg soil)	Plant species	% Cd removal	Reference
Citric acid	8	*Sedum alfredii*	17.5	Sun et al. (2009)
DTPA	5	*Sedum alfredii*	ND	Liu et al. (2009)
EDDS	5	*Phaseolus vulgaris*	1.10	Luo et al. (2006)
EDTA	3	*Phaseolus vulgaris*	1.40	Luo et al. (2006)
Glutamic acid	10	*Paulownia tomentosa*	0.007	Doumett et al. (2008)
Gallic acid	10	*Brassica juncea*	ND	do Nascimento et al. (2006)
HEDTA	1.8	*Helianthus annuus*	0.84	Chen and Cutright (2001)
Oxalic acid	10	*Brassica juncea*	ND	do Nascimento et al. (2006)
Tartrate	10	*Paulownia tomentosa*	0.005	Doumett et al. (2008)
Vanillic acid	10	*Brassica juncea*	ND	do Nascimento et al. (2006)

In recent years, many herbaceous species have been exploited to extract Cd using various chelants in pot experiments (Table 3.2A). Some studies have suggested that EDTA has no any positive effect in Cd extraction when the results were compared with controls (Zhuang et al. 2007; Kayser et al. 2000). This may be due to improper selection of hyperaccumulators and applied dose (Table 3.2A). This demonstrate that EDTA is suitable to enhance Cd-extraction of tested hyperaccumulators, even in an ideal growing conditions. On the contrary, a comparatively more enhancement has been reported by sulfur. The increased application rate of sulfur was proved to be supporting additive in Cd-extraction through *Helianthus annuus* (Table 3.2A; Zhuang et al. 2007).

DTPA is another potential chelating agent applied for Cd complexation. In several studies, the use of DTPA resulted in increased Cd solubility (Wu et al. 2004), thus increased plant uptake (Evangelou et al. 2007). Cd content in the leachate were directly correlated with the DTPA dose applied (Mehmood et al. 2012) and this impact was noticeable on the solubility of Cd even after 90 days period showing the high persistence of DTPA in soil (Nascimento et al. 2006). On the other hand, there are some severe drawbacks linked with DTPA use in soil. DTPA is less effective in Cd solubilization than EDTA and is light sensitive (Engelen et al. 2007; Kirkham, 2006). Moreover, the use of DTPA is toxic to plants due to negative effects on plant growth which makes it inappropriate for phytoextraction.

Except EDTA and DTPA, there are few more synthetic chelating compounds that control metal mobility but extensive research studies are needed to accurately interpret their role in terms of Cd dynamics in soil. NTA (Nitrilotriacetic acid) is one of those chelants which can bind with various metals and enhance their solubility

(Quartacci et al. 2006) but it is reported to be very toxic to plants. The NTA dose at 10 mmol/kg resulted in death of mustard plants within 48 h (Mehmood et al. 2012). Similarly, EGTA (ethylene glycol tetraacetic acid) and CDTA (Cyclohexanediaminetetraacetic acid) can considerably form complexes with higher proportions of Cd from the soil (Bolton et al. 1996) but studies are fewer.

To improve the efficiency of Cd-phytoextraction is always been a challenging task for scientific community who are actively working on soil remediation. Over the years, many researchers have claimed that Cd-extraction using chelating agent is an innovative approach to clean up Cd-polluted soils. Though, this type of assumption is a positive statement given by researchers as recently reported results demonstrate that <1% Cd-extraction of chelant-treated plants grown under in situ trails (Table 3.2A). This demonstrates that such hyperaccumulators require five decades to extract half of total Cd concentration from polluted soils. Since the removal rate depends on several factors i.e. biomass and bioaccumulation factor, and might change over time (Nowack et al. 2006; Grundler et al. 2005).

To reduce the soil environmental risks generated by using chelating agents is the another more important issue for chelating-supported extraction of Cd (Zhao et al. 2003). The non-biodegradable chelating agents are of serious concern due to their potential negative effects on soil ecosystem and leaching to aquifers and groundwater. EDTA has insignificant toxic effect on underground water reserves if the concentration is less than <2.2 mg/L (Meers et al. 2004). Though, the application rate of EDTA used in field trails is generally more than 1 mM (Table 3.2A). At maximum, plants can hardly take up 10% of EDTA applied (Grundler et al. 2005), most of the EDTA applied stayed in soils, posing serious environmental hazards. The leaching of mobilized soil Cd down to groundwater appears to be inevitable for all chelating agents. In brief, successful chelating-assisted Cd phytoextraction is still a blurred reality for the soil researchers (Grundler et al. 2005).

3.2.3 Cd Hyperaccumulators for Paddy Fields

Phytoremediation technology has been applied to prevent Cd entry into rice paddy fields. The use of hyperaccumulators, bioremediation and soil amendments are applied to large in situ remediation projects (Karkhanis et al. 2005; Sundaramoorthy et al. 2010). Naturally grown weeds and grasses i.e. *Cyperus kylinga*, *Cyperus rotundus*, *Ludwigia parviflora*, and *Marselia quadrifolia* are documented to grow successful in rice paddy fields and metal polluted soils (Lovley and Coates 1997). Hyperaccumulators i.e. *Nocceae caeruliensis*and *Pteris vittata* are suitable options to Cd-extraction in paddy fields of upland soils (Milner and Kochian 2008; Jadia and Fulekar 2008). Corn, Indian mustard, sorghum, and sunflower are also reported as efficient plant species for removal of Cd from metal contaminated sites whereas their potential to remediate Cd from rice paddy fields needs to be investigated (Ma et al. 2001; Zhao et al. 2003). The cultivation of sunflower crop over the Cd-contaminated soils has dual advantage of soil remediation and generating byproduct as biofuels which ultimately provide financial benefits. Crop rotation using Cd-accumulating plants is another viable option to curb Cd-contamination in paddy fields. The use of aquatic macrophytes i.e. *Pistia stratiotes*, *Lemna minor*, and *Eichhornia crassipes* could also be advantageous to control water soluble Cd content in lowland paddy fields and which are also reported to be effective in rhizofiltration (Chen et al. 2000).

Robinson et al. (2001) has reported that growth of aquatic plants such as *Althenia filiformis, Monita rivularis*, and *Elatine hexandra* performed well in extracting Cd content from contaminated rice paddy fields. The algal species were also documented three times more capable for Cd-cleanup in the flooded rice fields as compared to normal field conditions (Vandenhove et al. 2001). Continuous crop rotation followed by harvest reduces the concentration of Cd through the removal of crop residues that ensures periodic Cd removal (Reniger 1977).

3.2.4 Use of Herbaceous Species for Cd Removal

Herbaceous species have been identified as most suitable heavy metal hyperaccumulators so far. That's why most of hyperaccumulation studies have focused herbaceous species. More than one hundred and sixty herbaceous species have been studied for their potential to remediate Cd from contaminated soils through pot experiments in last decade. Much of the research studies are reported from Asian scientists. Abe et al. (2008) have reported that one hundred and one herbs have the potential to accumulate Cd content when they were grown under in situ conditions. From Asia, some weed species have been studied to assess their potential of hyperaccumulation (Barrutia et al. 2009).

Different herbaceous tested species have shown potential to remove Cd from 0.004% to 38.8% per year (Meers et al. 2004). *Nocceaecaerulescens* has been reported as well-known Cd hyperaccumulator and observed maximum Cd accumulation. At the same time, there are some recently identified Cd-accumulating species which are not included as Cd hyperaccumulators so far but possess exceptional qualities of Cd-extraction. Among such species, *N. caerulescens* has the potential to remediate Cd (upto 20%) of available Cd concentration in polluted soils (Zhao et al. 2003; Koopmans et al. 2008). Herbaceous species listed in Table 3.2A have been reported to be effective of different Cd extraction ranges in contaminated soils. It is assumed that Cd extraction would not change over time (Wei et al. 2009). If plant species (non-hyperaccumulators) listed in Table 3.1 exploited for the removal of Cd in pot experiments and field trails, then these species can be a worth addition in phytoextraction assets for contaminated soils. Huang et al. (1997) has reported that the real purpose of Cd-phytoextraction is to reduce metal content in polluted soils to safe limits over the period of two decades.

Overall, the soil pH and Cd enrichment in soil are influencing the capability of Cd extraction by herbaceous species in the contaminated soil (Yanai et al. 2006; Zhao et al. 2003; Koopmans et al. 2008). Based on data in the literature, it was shown that Cd extraction by hyperaccumulators was three times greater at soil pH than that of non-accumulators. This is the reason to justify the growing interest among the researchers to identify Cd accumulators. When soils less than 10 mg/kg Cd are termed as slightly to moderately contaminated soils (Meers et al. 2005), the average Cd extraction capacity of the plant species grown in these soils was nearly four times of that in highly polluted soils (Cd content greater than 10 mg/kg). Artificially polluted or spiked soils have more phytoavailable Cd than in anthropogenically contaminated soils. Cd is always more bioavailable in spiked soils than in anthropogenically contaminated soils (Tang et al. 2006; Prokop et al. 2003). Though, results of different phytoextraction studies have demonstrated that Cd extraction by herbaceous species grown in artificially polluted soils was 1.7% lower as compare to results of anthropogenically polluted soils. This unanticipated result may clearly be explained that the dose of Cd concentration applied in artificially polluted soils in pot experiment was sixteen times more in comparison to used anthropogenically polluted soils. In general, the herbaceous species have extracted 2 time more Cd content in acidic soils than in alkaline soils. This could be assumed due to more Cd phytoavailability in the acidic soils than that of alkaline soils (Fischerová et al. 2006; Wang et al. 2006).

3.2.5 Potential of Woody Species for Cd Cleanup

Plants producing high biomass and their potential use in Cd removal are the main characteristics of tree species have recently attained serious attention (Saraswat and Rai, 2011). Due to long life cycle of most tree species, they are generally considered to be unable to evolve rapidly enough to adapt to heavy metal–contaminated sites. Because of this limitation, it has been it has been presumed that few trees have developed a capacity to tolerate and accumulate Cd (Pulford and Watson 2003; Dickinson and Pulford 2005). Prolong life cycle of tree species is a fundamental drawback as hyperaccumulator and most of the time they remained unsuccessful in rapid extraction of metals from contaminated sites. Due to this reason, limited number of tree species has evolved to hyperaccumulation ability to remediate Cd.

Approximately twenty tree species have been exploited in pot experiments to test their potential to remove Cd from soils and most of these research studies reported from Europe. Genera *Salix* and *Populus* are the most extensively studied and fast growing tree species for Cd extraction (Dos Santos Utmazian and Wenzel 2007; Meers et al. 2007; Pulford and Watson 2003). Furthermore, it is worth mentioning here that a research group in Australia has identified the Cd accumulating capabilities of 2 *Populus* spp., and 6 *Salix* spp. for selection of Cd accumulator species (Mertens et al. 2006; Wu et al. 2010).

A total of eight tree species has been reported in various studies as potential hyperaccumulators for Cd extraction (Table 3.1). The highest Cd removal (11.2%) was reported in *Salix smithiana* (Table 3.2A), this removal efficiency is two times lower in comparison to herbaceous species. In addition, there are only 3 tree species

(Table 3.1) which are efficiently remove more 6% of the of the total Cd exists in soil (Vysloužilová et al. 2003).

As discussed earlier that the limited number of tree species have been studied for Cd extraction in the fixed quantity of soil samples in pot experiments that inhibited their growth compared with herbaceous species (Dos Santos Utmazian and Wenzel 2007). Different research studied has shown that tree species (willows) are not suitable for Cd extraction from heavily contaminated soil due to very low biomass production (Arnold and McDonald 1999). Hence, it is recommended that non-hyperaccumulator tree species should be testedin field trails over the soils of different Cd contamination levels to assess their potential of Cd uptake (Pulford and Watson 2003). Based on the results of such studies, newly identified tree species can be used in widespread application (Jensen et al. 2009).

3.2.6 Soil Amendments for Cd (im)mobilization

Addition of sewage sludge and agriculture derived compost including chelating agents to contaminated soils improve soil ecosystem health, thus supporting plant growth. In addition, such additives also have mobilizing effects on metals because

Table 3.2B Selected studies on the prospective value of soil amendments in themobilization of Cd in soils

Soil Amendments	Plant species	Concluding remarks	Reference
Poultry manure	*Avena sativa* L.	Poultry manure increased the available Cd concentration during three year study.	Hanč et al. (2008)
Rice straw, Clover	*Sedum plumbizincicola*	Increased Cd in *Sedum plumbizincicola*. No increase in soil solutions.	Wu et al. (2012)
Biochar, Green waste compost	*Lolium perenne* L. var Cadix	Cu and As concentrations in soil pore water increased more than 30 fold after adding both amendments, whereas Zn and Cd decreased significantly.	
Sewage sludge	*Vigna radiata* L.	Cd concentrations in mung bean exceeded the permissible limits.	Singh and Agrawal, (2010)
Sewage sludge	*Beta vulgaris*	Sewage sludge increased metal uptake in root and shoot of Beta vulgaris. Concentrations of Cd, Ni and Zn were more than the permissible limits.	Singh and Agrawal, (2007)
Sewage sludge, Compost	*Zea mays*	Amendments increased dry matter, and caused higher concentrations of Cd in roots and shoots, but did not exceed the guidelines.	Kandil et al. (2012)
Manure, Sewage sludge, Compost	*Zea mays*	Cd content increased in seeds and grains of spring rape and spring triticale, but were within the guideline limits.	Izhevska, (2009)

humic acids present bind metals such as Cd (Table 3.2B). However, the organic amendments can impact phytoavailability of soil HMs through various ways. Biochar has the potential to decrease 300 times Cd content through sorption (Wuana and Okieimen 2011; Adriano et al. 2004). Wu et al. (2012) reported that traditional organic materials (cloverand rice straw) can be much more effective and environmental friendly amendments than the chelating agent, Ethylenediamine-N, N-disuccinic acid (EDDS) in enhancing phytoremediation efficiency of Cd contaminated soil. Wang et al. (2013) reported that, arbuscular mycorrhizal fungi and organic manure show correlated effect in phytoextraction and phytostabilization of Cd.

However, in some other occasions, these amendments can also add soluble organic ligands, There by increasing metal mobility and leaching to groundwater (Beesley and Marmiroli 2011). The amount of organic matter has been shown to affect metal movement in soil. The idea of using organic soil amendments has frequently been proven efficient in Pb phytoextraction. Though, its effectiveness in phytoextraction of Cd is always un clear because of the fact that Cd in polluted soils is generally readily phytoavailable (Mahar et al. 2015, 2016).

Furthermore, inorganic fertilizers have been shown to be mobilizing agents. Kirkham (2013) have identified some articles that studied mobilization of heavy metals using fertilizers (Shuman 1998; Houben et al. 2013). Munksgaard et al. (2012) showed that superphosphate fertilizer had opposing effects on metal mobility when applied to mine waste polluted soils. The contaminated soils contained sulfide and sulfate-rich waste material from mining sites in Australia. Munksgaard et al. (2012) has concluded that fertilizer was not effective to stabilize the phases of soluble metal in a sulfate-rich soil.

Immobilization of toxic heavy metals can be achieved mainly by complexation, precipitation, and adsorption, reactions which effects the redistribution of metals from solution phase to solid phase, thus reducing their transport and bioavailability in the soil (Madejón et al. 2006). Soil additives are termed as soil amendments which improve soil physical properties i.e. water permeability, water-holding capacity, aeration, soil structure, and water infiltration (Porter et al. 2004). There are different soil amendments used to decrease the bioavailability of Cd in plants (Table 3.2C). Soil amendments reduce Cd uptake through different mechanisms i.e. adsorption, sorption, stabilization, and immobilization of soil heavy metals (Munksgaard et al. 2012; Tanhan et al. 2011).

Organic amendments must be replaced periodically after the breakdown of previous one to sustain the adsorbing ability of heavy metals. Amendments primarily effect Cd partitioning of soil liquid and solid phase. Organic amendments have the sorption properties which support the enhancement of Cd-binding properties in contaminated soils as compared to normal soils (Uchimiya et al. 2011). Organic amendments make a layer over a particulate matter on surface and subsurface coating of soil and could function as metal binder. Such additives are categorized through the presence of tannins, cellulose, carbonates, and lignin, which enhance natural potential of soil to keep intact metals (Beesley et al. 2011; Sauvé et al. 2003). The content of dissolved organic carbon increases as the addition of organic amendments in soil

Table 3.2C Selected studies on the promising soil amendments in the immobilization of Cd in contaminated soils

Amendments	Cd Enrichment	References
Palygorskite; Sepiolite	Highly polluted mine soil	Álvarez-Ayuso et al. (2003)
PR waste clay	Sewage sludge	Gonzalez-Davila et al. (1995)
PR (NCPR)	Smelter-contaminated soil	Basta et al. (2001)
Hydroxyapatite (HA)	Cd solution (spiked with $Cd(NO_3)_2$)	Mandjiny et al. (1998)
Aqueous palygorskite, sepiolite and calcite	Cd-amended soil	Shirvani et al. (2007)
$Ca(OH)_2$, Sepiolite	Cd-contaminated paddy field	Álvarez-Ayuso et al. (2003)
Granular bentonite	Aqueous solutions	Fernández-Nava et al. (2011)
Natural zeolite (clinoptilolite)	Artificially contaminated soil	Chlopecka, (1996)
$Ca(OH)_2$ (8, 15 and 22 Mg/ha)	Limed biosolids (spiked with $Cd(NO_3)_2$)	Basta and Gradwohl (2000)
$Ca(OH)_2$ (8, 15 and 22 Mg/ha)	Sewage sludge	Brallier et al. (1996)
$Ca(OH)_2$ and $CaCO_3$(0–1120 kg/ha)	Sand	Chaney et al. (1977)
$CaCO_3$, $Ca(OH)_2$, $CaSO_4.2H_2O$, Oyster shell meal	Heavy-metal-contaminated soil	Hong et al. (2007)
Red muds, natural zeolite, lime	Polluted mine soil	Garau et al. (2007)
Zeolite, compost, calcium hydroxide	Polluted soil	Castaldi et al. (2005)
Lime, red mud	Zn/Pb smelter site	Gray et al. (2006)
Cyclonic ashes, lime	Farmland soil	Ruttens et al. (2010)
KH_2PO_4	Cd-amended artificial soil	Bolan et al. (2003a)
$(NH_4)2HPO_4$	Smelter-contaminated soil	McGowen et al. (2001)
Apatite, zeolite, Fe-oxide	Spiked with flu dust	Chlopecka and Adriano (1997)
KH_2PO_4, $Ca(H_2PO_4)_2$	Variable charge soil	Bolan et al. (2003b)
Hydroxyapatite, phosphate rock, triple superphosphate, diammonium phosphate	Spiked with $CdSO_4$	Chen et al. (2007)
Hydrous Mn oxide	Smelter polluted soil	Mench et al. (1994)
Fe-rich waste (Fe (hydro) oxides) with redox cycles	Arable site	Contin et al. (2007)
Mn oxide	Farmland polluted by wastewater	Cheng and Hseu (2002)
Fe oxide waste by-product	Cropped contaminated soil	Chlopecka, (1996)
Biosolid	Spiked with $Cd(NO_3)_2$	Bolan et al. (2003b)
P-rich biosolid	Spiked with $Cd(NO_3)_2$)	Soon (1981)

(continued)

Table 3.2C (continued)

Amendments	Cd Enrichment	References
Papermill Sludge, Sewage Sludge	Agricultural soil	Merrington and Madden (2000)
Biosolid	Spiked with $Cd(NO_3)_2$	Brown et al. (1998)
Biosolid	Spiked with CdCl	Weggler-Beaton et al. (2000)
Organic matter	Rice paddy field	Kashem and Singh (2001)
Chicken manure compost	Spiked with $CdCl_2$	Liu et al. (2009)
Compost	Smelter polluted soil	Ruttens et al. (2006)
Humus, compost	Rice paddy soils	Ok et al. (2011)
Biosolid, wood ash, K_2SO_4	Wetland tailings repository	DeVolder et al. (2003)
Hard wood biochar	Polluted soil	Beesley et al. (2011)
Chicken manure and green waste biochars	Shooting range soil	Park et al. (2011)
Zero valent iron (ZVI), lime, humus, compost	Metal-contaminated paddy soil	Ok et al. (2011)

which reduces the phytoavailability of Cd in soil through making of DOC–metal complexes (Berg 2000; Han et al. 2001). DOC–metal complexes releases fulvic acids and humic acids which enhance the metal adsorbing capacity of organic additives. The hydroxyl and carboxyl groups are in great abundance in complexing agents which make Cd-binding (Jayaram and Prasad 2009).

The effective use of seed powder of weeds in soil may act as donor of carboxyl group which react and precipitate Cd (Lee et al. 1993; Knox et al. 2001; Sloan and Basta 1995). Application of weeds and economically important plants i.e. bamboo that have properties to function as soil amendments for extensive in situ soil remediation through charcoal and powder prepared for plant material which absorb heavy metals (Joseph et al. 2010; Moreno et al. 1999). Carbon buffering of soil can be increased by applying organic additives in alkaline form (Impellitteri and Scheckel 2006). In addition, such amendments enhance the pH of soil which force Cd-sorption in soil. Before applying sewage sludge as an organic amendment, a pre-assessment must be done as this material contains Cd contamination (Lalhruaitluanga et al. 2010). Exploitation of vermicompost reported to be suitable for Cd immobilization, has some significant drawbacks as it makes changes in soil structure and increase soil porosity due to compost addition into soil which increase the growth of root (Sebastian and Prasad 2013; Komarek et al. 2013; Kumpiene 2010; Hartley et al. 2004). The increasing growth of roots supports the hyper accumulation of Cd in rice crops as root to Cd contact increases. In addition, there is a further limitation that when soil organic amendments start to degrade then immediate need of periodic addition of additives would be increasing to retain the objective of heavy metal immobilization (Kookana et al. 2011; Feng et al. 2007).

In contrast to natural organic amendments, synthetic amendments are very effective due to their possible modification to strengthen immobilization process.

Ammonium phosphate and calcium crop fertilizers are documented as potential chemical stabilizers of metals (Mendoza-Cózatl et al. 2003; Brown et al. 2003; Zorpas et al. 2000). Therefore, the combinations of fertilizer consist of phosphorous and sulfur support the Cd-immobilization under reducing conditions in contaminated soils (Basta and McGowen 2004; Li et al. 2000). The use of ammonium fertilizer and diammonium phosphate as soil amendments has significant effect on Cd-immobilization in soil during the nitrification process (Harter and Naidu 1995; Bolan et al. 2003b; O'Connor et al. 1984; Krishnamurti et al. 1996). Clay minerals i.e. bentonite, kaolinite, palygorskite, perlite, sepiolite, zeolites etc. are additional potential soil amendments due to its flexible surface charge against pH, higher Brönsted and Lewis acidities, more cation exchange capacity, and high specific surface area (Gray et al. 2006; Fernández-Nava et al. 2011). These adsorbing agents have some problems i.e. formation of stable colloidal suspension due to water infiltration ultimately reduce soil permeability. Such issues can be avoided through pretreatments i.e. granulation (Su-Hsia and Reuy-Shin 2002; Lin and Juang 2002). Activated carbon is also a promising Cd adsorbent in soil but cost effectiveness is a disadvantage of it. $CaCO_3$ is commonly applied to decrease plant metal uptake and to increase soil pH (Zupančič et al. 2012; Knox et al. 2001). The periodical replacement of $CaCO_3$ must be conducted to sustain the soil pH while considering the use of $CaCO_3$ as soil additive. Although, soil amendments are commonly applied to clean up contaminated sites but to point where such amendments could curb metal uptake is controversial as they exhibit deviation in metal binding due to variations in properties soil (Garau et al. 2007; Pierzynski and Schwab, 1993; Levi-Minzi and Petruzzelli, 1984).

3.2.7 Microbial-Assisted Phytoextraction

Application of microbes in the remediation of Cd faces some challenges due to non-biodegradable nature of Cd. Whereas, the bioconversion of Cd complexes and Cd-microbial immobilization restrict available Cd content to hyperaccumulators ultimately remediate paddy fields. Bioremediation of Cd- polluted sites depends on several factors i.e. metal concentration, Cd-binding to cell walls, calcium level, pH, methylation of Cd, and ionic strength (Jézéque and Lebeau 2008). The phosphate, carboxyl, hydroxyl, or sulfhydryl functional groups are the important sites on bacterial cell walls for Cd adsorption. Cd-immobilization occurs in contaminated soils due to such property. In comparison to clay soil, the sorption of Cd through bacteria was demonstrated to be evident in sandy soil (Rajkumar et al. 2010).

Sarin and Sarin (2010) has reported that that *Pseudomonas fluorescens* G9 and *Bacillus subtilis* Tp8 are the biosurfactant producing bacteria which have the potential to remediate Cd-contaminated soils. The phytoavailability of Cd can also be reduced using sulfate-reducing bacteria which precipitate Cd due to formation of Cd-sulfide complex. The use of alginic acid (also termed as alginate or algin) as microbial inoculation in contaminated soils is also capable of decreasing exchangeable Cd content

(Vig et al. 2003). Desorption of Cd may occur due to alginate mineralization if the replacement of alginate beads would not be made in these approaches.

The bacterial species which produce siderophore are getting more interest among soil researchers forremediating Cd-contaminated soils due to greater their capacity to mobilize Cd (Christofi and Ivshina 2002). Bioaugmentation is another fast-growing microbial remediation technique which exploits microorganisms to increase metal mobility and availability. Fuloria et al. (2009) have reported that *Rhodococcus* sp., *Variovorax paradoxus*, *Pseudomonas fluorescens* Pf 27, and *Flavobacterium* sp. enhance exchangeable and water-soluble Cd concentration in polluted soil. This in turn increased the Cd uptake and plant biomass of Brassica juncea.

Dell'Amico et al. (2008) and Rani et al. (2009) also reported such same findings that when *Pseudomonas monteilli* 97AN and *Pseudomonas putida* 62BN were inoculated in soybean including *Pseudomonas fluorescens* ACC9, *Pseudomonas tolaasii* ACC23, *Mycobacterium* and *Alcaligenes* species ZN4 inoculated in canola. As rice crop is prone to different microbial infections so the use of microbes for Cd removal in the rice paddy field must be handled carefully. Table 3.3 shows that different microorganisms have the potential to improve Cd removal when they coordinate with hyperaccumulators in the soil system.

Phytoextraction accompanied with symbiotic association through using metal chelating agents (Table 3.3) is another significant approach in the process of phytoremediation (Joschim et al. 2009). Chelation of Cd inside fungus body, adsorption of Cd to chitin in fungal cell walls, and precipitation of Cd as polyphosphate granules in the soil are the main features of mycorrhiza-assisted soil remediation (Prasad et al. 2010). The symbiotic association of mycorrhiza with hyperaccumulators through hyphal network which goes down to root zone increases water use efficiency and supports efficient mineral uptake (Wright et al. 1998). Association of mycorrhiza certainly promote efficient uptake of minerals particularly phosphorous due to its precipitation ability for Cd. Therefore, mycorrhiza minimizes the Cd content near root zone. In addition, mycorrhiza association also supports the increase in plant biomass production which causes dilution of Cd through expended tissues. During the maturation period, this process restricts the entry of Cd into rice grain (Upadhyaya et al. 2010). The main crux of above facts is that phytoextraction of Cd polluted soil is being supported through the combined effect of mycorrhizal association and chelating agents. There is an enormous scope of research in the field of mycoremediation i.e. how mycorrhiza is impacting on heavy metals transformation to paddy fields (Lin et al. 2016).

3.2.8 A Comparative Analysis of In-Situ and Ex-Situ Experiments

On historic note, the Cd extraction through hyperaccumulators species conducted in in *ex situ* trails has always been overrated in comparison to those executed in *in situ* experiments. However, less work has been done on the correlation of lab scale studies and field trials simultaneously. The most overrated species is *Arabidopsis halleri* as potential hyperaccumulators. This hyperaccumulator when grown in pot the average % Cd extraction was 5.13% whereas 0.01% that of in situ experiment. Hyperaccumulator could not adapt wild environmental conditions and this could be the reason behind low biomass production (Robinson et al. 2006). In addition, diversity of soil contaminants may be the further reason in wild conditions (Ciura et al. 2005; Luo et al. 2006; McGrath et al. 2006). Both temporal and spatial variability of soil pollutants could create challenges for plant roots to take up Cd from rhizosphere. *Phaseolus vulgaris* is the only exceptional hyperaccumulator which has shown 50% more Cd extraction in the *in situ* experiment (Dickinson and Pulford 2005). Most of hyperaccumulators grown is ex situ experiments have always been overrated the Cd extraction rates about ten times in comparison to the observations reported in the in situ trails. *Zea mays* and *Thlaspi caerulescens* are the perfect examples of this phenomenon. A significant number of ex situ and in situ experiments have conducted with these two species. It is worth mentioning here that the dataset of Cd extraction studies was presented in this critical review are based on the initial findings but could provide suitable guideline for future Cd remediation research. Herbaceous species grown under lab conditions are well researched thus it is high time to exploit them in field conditions. It is important to mention here that field trails have time constrains and comparatively costlier than lab scale studies (Dickinson and Pulford 2005).

3.3 Concluding Remarks and Future Research

In recent years, a significant development has been made in Cd phytoextraction than ever before, however this approach is not yet ready for extensive field application. The optimum results of Cd-phytoextraction are obtained in soil contaminated with Cd less 5 mg/kg thus Cd Phytoextraction is suggested for moderately Cd-contaminated soils. Cd Phytoextraction is recommended for moderately Cd-contaminated soils, especially those contaminated only by Cd, considering that most of the encouraging results from in situ experiments recorded in soils contaminated only by Cd at moderate level of <5 mg Cd/kg contaminated soils. In practical, there are several cases where other pollutants (organic or inorganic) may be present with excessive levels in Cd-contaminated soils. The presence of co-pollutants decreases the annual percentage of Cd removal by phytaccumulators through decreasing Cd uptake or restricting plant growth, thereby, making a lengthy Cd-phytoextraction drill. In addition, supportive particular cleanup approaches are desired to remediate the co-pollutants, as there are limited number of hyperaccumulators which can accumulate more than one pollutant. More research is needed to elucidate effect of pH and EC in water and soil systems that govern transformations of Cd both in lowland and upland rice paddy fields. Analysis of solution-phase and solid-phase speciation of Cd in water and soil using advanced spectroscopic-based techniques must be studied. Further research is required to identify biochemical mechanisms involved in the

Cd uptake in rice grains. Not more research has been conducted on the rhizosphere processes underpinning effective phytoextraction technology for Cd cleanup from contaminated soils. Likewise, plant growth supporting bacteria and fungi (mycorrhizae) play critical role if they are included in Cd-phytoextraction process. Hence, more research should be conducted to select and identify new microbial strains with such functions and for better understanding of interactions among the players in the rhizosphere i.e. plant roots, among metals, microbes, and soil system. Furthermore, the methods for the disposal of Cd-enriched biomass required to be more investigated. On practical note, an integrated approach using different Cd removal option i.e. hyperaccumulators, chelators, microbes and soil amendments must be exploited but integrated management must be compatible with local environmental factors to achieve ecologically sustainable Cd-phytoextraction.

Acknowledgments The financial assistance from 2012 Chinese Government Heavy Metals Pollution Control Special Fund is gratefully acknowledged.

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Chapter 4
Climate Change and Costal Plant Lives

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Abstract Climate represent the earth's atmosphere over a given region, defined by certain factors viz. temperature, air pressure, humidity, precipitation, sunlight, cloudiness, and winds. While, climate change is the earth's climate periodic modification brought as a result of atmospheric changes as well as atmosphere and other various geological, biological, geographic factors interaction between them within earth system. The atmosphere is like the dynamic fluid which is always in the continuous motion. The direction of motion and physical properties and its rate are stimulated by different factors, including the geographic position, solar radiation, ocean current, chemistry of atmosphere, continents geographic position, the location and orientation of mountain ranges, and vegetation growing on the land surface. Global sea-level rise is one of the major outcomes of global warming (12–22 cm occurred during the twentieth century), and several other climate models project an accelerated rate of about 0.18–0.59 m rise in global sea-level in coming decades. Such climatic changes have altered the marine ecosystem greatly.

Keywords Climate change · Global warming · Ecosystem · Costal plants

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_4

4.1 Climate

Climate is the condition of every day's weather about the period of thirty years of a specific geological position. It is usually measured by the different factors such as temperature variation, wind, pressure of atmosphere, rainfall, humidity, atmospheric particle count and other variable factors in a specific geological hemisphere for a long time (Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). It is different from weather because the weather is the short-term condition in a given region of these variables. Climate of a specific region is due to the climate system which is composed of five basic components: Biosphere, lithosphere, hydrosphere, cryosphere and atmosphere. Different factors affect the climate of a location for example the latitude and altitude, as well as the water bodies nearby and their currents.

Temperature and precipitation are the two variables on the basis of which climate is classified.

The most frequently used classification scheme is the Köppen climate classification. In the study of climate change and diversity, Thornthwaite system mainly incorporates the evapotranspiration and the data of temperature along with precipitation rate, from 1940s.

The regional climate is mainly describe by the origin of air masses and for their study we have two very useful classification systems like the Spatial Synoptic and Bergeron Classification systems.

The study of ancient climates is called Paleoclimatology. Before the nineteenth century, climate observations are not directly available but paleoclimates have confirmed from different variables that are abiotic evidences such as the sediments found in the beds of ice cores and in the beds of lakes, and living or biotic such as coral and tree rings. These climatic models are the mathematical models of past, present and future climate. Climate change occurs by different factors over short and long timescales i.e. global warming, which results in redistributions. For example, the change in the mean annual temperature about 3 °C corresponds approximately 0.5 m in elevation or 187–248 Miles in latitude (in the temperate zone) shift in isotherms. Therefore in response to shifting climate zones, the species are expected to move towards the poles in latitude or upward in elevation.

4.2 Climate Change

Climate change, Earth's climate periodic modification brought as a result of atmospheric changes as well as atmosphere and other various geological, biological, geographic factors interaction between them within earth system. The atmosphere is like the dynamic fluid which is always in the continuous motion. The direction of motion and physical properties and its rate are stimulated by different factors, including the geographic position, solar radiation, ocean current, chemistry of atmosphere, continents geographic position, the location and orientation of mountain ranges, and vegetation growing on the land surface.

Through time, all these factors change. Some factors changes at very short timescales for example surface vegetation, the heat distribution within the oceans, atmospheric chemistry.

Others change over very long timescales, like the location and height of mountain ranges and the position of continents.

Therefore climate varies at every conceivable timescale because climate results from the motion and the physical properties of atmosphere. Climate is sometimes called the average weather of a specific location with such features like humidity, precipitation, windiness and temperature. The more accurate definition would be its mean state and the variability of these variables over some extend of time. Both the statements about climate confirms that the weather is always variable, instable in the atmosphere. As weather changes from day to day so therefore climate also varies, from the cycle of day-night on daily basis up to geologic time hundreds of millions of years long. So the climate variation is a redundant expression.

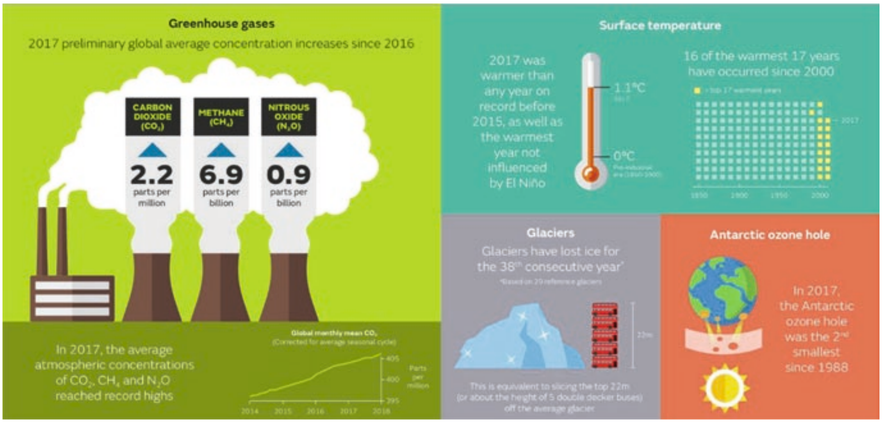
Not even two years are same nor any two millennia. This article is about the variation of climate and the changes occurred within the natural feature's integrated set and the phenomenon is called the Earth system. The evidence about climate change is well elaborated as the principal mechanisms that are the main causing agents throughout the earth history.

At the end, well explained description about the climate change ranging from all geologic time to the life span of humans is given over many different time scales.

> *Climate change is the long term shift in the pattern of earth's weather and temperatures. This planet has had many ice ages and extreme temperature seasons since its birth about 4.6 billion years. So what's wrong now?*

About 11,000 years ago last ice age ended and the climate of earth has been relatively stable along with an average of 14 °C global temperature. But the global temperature have risen during 20th and 21st centuries due to the rise in atmospheric CO_2 (carbon dioxide). Atmospheric carbon dioxide has increased by over 40%, the level that is recorded in at least 800 thousand since the Industrial Revolution. Increase in temperature causes the warming of our climate system and the multiple indicators are alarming that our climate is changing. The snowfall rate is decreased and ice have been diminished, rise in the sea level is observed, greenhouse gases ratio in the atmosphere is exceeded from normal to critical level, temperature of atmosphere and the oceans is increased.

Infographic issued by the Bulletin of the American Meteorological Society, given below shows the major climatic changes.



4.3 Higher Temperatures

About 1 °C Global average surface temperature is increased since the 1850s. In the instrumental record each of the last 3 (three) decades has been successively warmer than any other preceding decade and since the year 2001, 16 of the 17 warmest years on record have occurred during these years.

4.4 Changing Rainfall

In the mid-latitudes of the northern hemisphere, the rainfall has increased since twentieth century beginning. Changes between the seasons of different regions are also observed. For example the average decrease is observed in the UK's summer rainfall while increase in winter rainfall. Evidences also confirms the heavy rainfall become more intensive over the North American region. Rainfall long-term records are needed to resolve any trend from natural changes for some areas.

4.5 Climate Change Threats to Costal Plan Lives

Behavior of the species are mainly affected due to the severe changes in the seasons (such as spring starts before its actual time and autumn starts later), like birds are shifting the migration pattern and the butterflies appear early in the year.

4.5.1 Retreating Glaciers

The shrinkage rate has been increased from last decades due to melting of glaciers all over the globe that exist in the Andes, Himalayas, Alaska, Alps and Rockies.

4.5.2 Sea Ice

Since the late 1970s, decline in the arctic sea-ice has been observed in extent by about 3.9% or 0.6 million sq km per ten year time. Since 1979, the decrease in arctic sea-ice extent by 13.4% in summer per decade. While Antarctic sea-ice is more stable at the same time, since autumn 2016, most of the areas had been at very low levels.

4.5.3 Ice Sheets

The world's major fresh water reservoirs (The Greenland and Antarctic ice sheets) are melting at an accelerating rate.

4.5.4 Coastal Areas

Where water and land join to create an environment with other environmental factors, such areas are known as coastal areas. Hurricanes and El Niño, responsible for the migration of aquatic and other forms of life, the significant amount of damage to ecosystems of coastal areas, reduction in the food supplies and ecosystem disturbance and unbalanced ecosystem. Many acres of coastal region's wetland has been destroyed by Katrina, Hurricanes Andrew and Rita around the Mexican gulf and Florida but still not yet the effects of this destruction are clear that what will happen in future. Coastal areas facing the most significant problems such as runoff from agricultural, industrial and municipal areas. This can result in the higher pollutant level in the waters of coastal areas, it also nourish the algae which can be harmful for both aquatic life and humans. According to the fisheries, coastal areas are particularly important. Coastal fish population and their habitats are at great risk due to the potential contamination of ocean waters and coastal, overfishing and over fishing practices. While pressure on native stocks can be reduced by fish farming (farm-raised fish), these farm-raised fishes can escape and compete with native breed and become a dominant specie. Through cruise ships and marine vessels these invasive species are introduced to the coastal waters.

4.6 Sea Level Rises

Global mean sea level has been rise by more than eight inches since 1900. In recent decades the sea level rise has increased over the last century around 1.7 mm per year to 3.3 mm per year since 1990s.

4.6.1 Sea Level Rise and Climate Change

Since late nineteenth century, the increase in the mean surface temperature of globe is observed which got the attention of academia and governments in very short duration.

IPCC (Intergovernmental Panel on Climate Change) measured the global climate change effect five times from 1990s on human socioeconomic system and natural ecosystems.

According to the 5th IPCC report of the ocean temperature and global combined land data showed 0.89 °C increase over the period of 1901–2012. Over the period of 1901–2010, the mean sea level worldiwde is increased by 0.19 m and between 1901 and 2010. mean sea level rise rate was 1.7 mm per year. Rise in the temperature warms the ocean water and causes the expansion of sea level and also melt the sheets of ice along with the glaciers which contributes the rise of three-quarters.

From last 800,000 years, the atmospheric carbon dioxide, nitrous oxide (dinitrogen monoxide) and methane were 390.5 ppm, 390.5 ppb and 1803.2 parts per billion were higher than experienced and greater than before by 40, 20, 150% since before the industrial era.

Since the mid-twentieth century, the changes observed in the intensity and frequency of extreme events of weather climate are intensifying on world wide scale. Through the observation of frequency of extremely warm and extreme precipitation events, it is clearly showed. Coastal plant life major role is the vegetation in that wetland ecosystem.

In global ecosystem, the role of vegetation is obvious. Particularly, under the pressure of climate change and the activities of human beings, the vegetation of wet coastal land play an important role which is concise as under:

4.6.1.1 Carbon Fixation, Storage of Carbon

For the greenhouse gases, coastal wetland is the vital “source” and “sink”. Most important role of the “sink” is that the wetland vegetation have maximum rate of sequestration of carbon with the minimum rate of methane emission. UNEP (United Nations Environment Program) and FAO (Food and Agriculture Organization) along with the other 4 departments in 2009, released the report about ocean carbon sink. According to United Nations Environment Program (UNEP), most of the

Fig. 4.1 The banks of the Daly Estuary (Australia), is covered by Mangrove roots

world's biomedical carbon is taken by the vegetated habitats of oceans and called the blue carbon like by seagrasses, salt marshes and mangroves.

Coastal wet land vegetation biomass is 0.05% more than terrestrial vegetation. About 862–1650 Tg CO2 (Tg = 1012 g) of carbon is captured and stored per year through the blue carbon ecosystem which is ten-fifty times more than forest.

4.6.1.2 Disaster Mitigation

In the rainy season as buffer zone (between the oceans and land), the vegetation of coastal wet land is capable to store sufficient amount of water and reduces the flood disasters pressure. The Root system of the vegetation have an essential role of formation of land which also absorb the intertidal sediments which mitigate the erosion action on coast line by waves. The notable example is the mangrove forest that is also known as "Chlory the Ocean Guard" which reduces the damage ratio by protecting the crops from extremely saline and strong winds. In Fig. 4.1, the upper bank of Daly Estuary, Australia, is covered by mangrove roots which show resistance against the erosion of upper banks but it's less useful in the case of lower banks undercutting.

1. **Marine habitat**:

   Habitat for fish, waterfowl of winter, shrimp and endangered rare species (manatees or sea cows, turtles etc.) Is provided by the aquatic vegetation communities are found in marine.
2. **Plant purification**:

In the surrounding water, submerged aquatic vegetation's tissues have the concentration of heavy metal of about 100,000 times higher than others. Some species can successfully degrade the sewage like water hyacinth, bulrush etc.

4.7 Vegetation Succession Under Climate Change with the Factors of Driving and Response Analysis

Under acceptable natural condition, the vegetation of the coastline shows the encouraging succession. However, coastal wetland vegetation cannot tolerate the environmental factors effect along with the global climate change otherwise it will leads towards the regressive succession of vegetation and landscape fragmentation of vegetation and some other magnitudes.

4.7.1 Progressive Vegetation Succession Under Natural Environments

To evaluate the succession law of wetlands vegetation, 3 kinds of habitats are chosen as example that are discussed below:

1. Estuary delta: In estuarine delta the distribution of vegetation is zonal because of salinity of soil difference in three-dimensional distribution. From the bare flat, the community of vegetation succession starts such as wing-alkali those vegetation appears first that are highly salt tolerant. The community of medium-low vegetation appears as increase in litter in surface and vegetation such as Reed-Alkali.

   The non-zonal top community (Tamarix Chinesis) formed eventually due to ground water level reduction and increase in topography.
2. Tidal flat wetland: Tidal flat wetland vegetation zonal distribution is horizontal. From the vegetation that are salinity tolerant, succession starts along with coastal beach uplift, soil salinity decreases along with perennial wet plant invasion and process of Desalination of Soil accelerated by vegetation litter. The community of medium vegetation becomes dominant and soil is further biochemical.
3. Mangrove wetlands: Along with the gulf or estuary coastline, the forest of mangrove often form that is a strip distribution. From the non-mangroves plants the pioneer communities often formed having the ability to stand against the strong waves of wind and leanness. Typical mangrove communities with the demineralization development, developed the dominant position in their respective ecosystem. Reduction after soil salinity, the formation of pioneer community starts while Succession of vegetation is always dependent on the salinity resistance, resistance against the waterlogging and barren species, no matter what type of the coastal wetlands are. Gradually then environment achieve stability which play an important role in the growth of vegetation. At last, the stable and whole comprehensive ecosystem for the vegetation is formed. Development of the community of wetland vegetation beside table of water range is elaborated in Fig. 4.2.

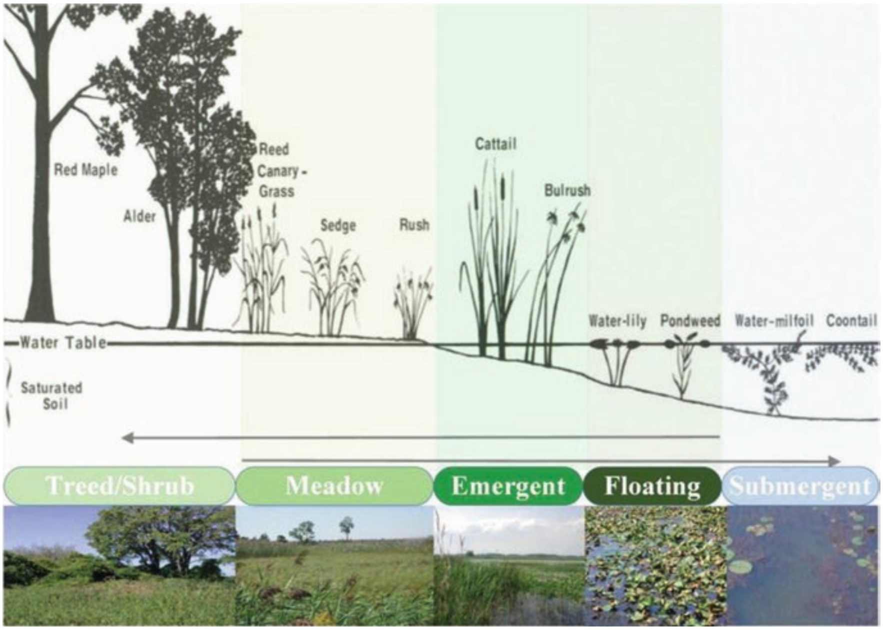


Fig. 4.2 Development of vegetation community with continuum of water table (Mortsch et al. 2006)

4.7.2 *Vegetation's Successions Driving Factors Under Climate Change*

Succession of vegetation characteristics along with the effect of elevation and geographic position, it also depends on the factors like soil nutrient, water content as well as with the activities of human beings. Under climate change, some factors become dominant and magnified.

4.7.2.1 Changes in the Elevation Relative to Habitat

Sea level rise can be influenced by increase in coastal wetland elevation in the result of accumulation of tidal flat sediments. First of all, if the rate of sediments accumulation is nearly same to the rise in sea level, the coastal wetland relative elevation will be constant and the effect on vegetation growth will be minimum by the sea level rise, as shown in Fig. 4.3a. Furthermore, as in Fig. 4.3b, in case of increase in the sediment accumulation rate than the sea level rise, this will be in favor of vegetation habitat area because the growth area will enlarge. Thirdly, as in Fig. 4.3c, the growth and survival of the vegetation will be affected in case the rate of sea level rise is greater than sediment accumulation rate because it will result the decrease in relative elevation and will promote the flooding frequency as these situations can

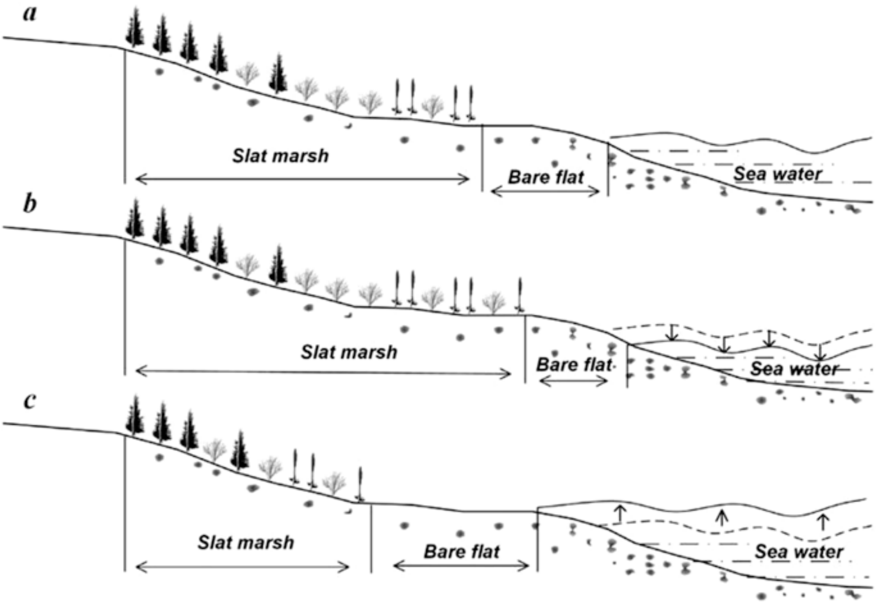


Fig. 4.3 Coastal wetland vegetation's sketch in response of rise in sea level. (*a*) Unchanged sea level; (*b*) Sea level dropped; (*c*) Sea level raised

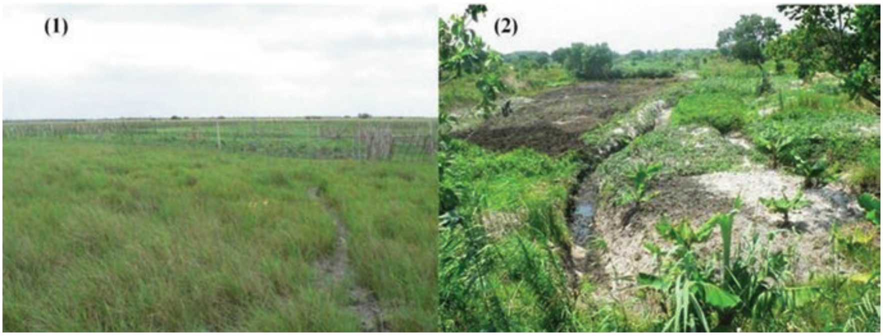


Fig. 4.4 (*1*) Economic plantations on coastal plain of Maputaland from the last 20 years; (*2*) drained and destructed wetland

diminish the life of plants By the Suggestion of some other researches, in the upper layers of soil, the processes of accumulation is slower than physical-biological time-effect. In the coastal wetland new shallow strata just like estuary delta, layer of soil is compressed that is under the artificial coastal engineering action's, which is easy for soil subsidence.

4.7.2.2 Coastal Habitat's Net Loss

Under the influence of sea level rise, the coastal wetland can be preserved by occupying formerly upland and inland sites extension. However, coastal wetland ability to move landward depends on the topography relationship. As the sites of lower elevation become submerged, the boundary of landward marsh slope may expand. The effective barrier of slop will inhibit the growth of plant communities in such geographic location and as a result, the area for coastal vegetation is squeeze. In few typical coastal wetland, the movement of marsh edge is modeled by the scientists of USGS and the University of Duke that this is not just the rise in sea level but also activities of human beings that stimulates inland marsh movement. Rate of sediment accumulation is very low as compared to human reclamation rate, may be speeded up in the initial stages of inland evolution and reclamation of coastal wetland. In Africa, the survived agricultural plantation took place on the Maputaland coastal plain's wettest zones of wetland, as shown in the Fig. 4.4(1). However, coastal wetland natural evolution purpose is different from human reclamation, so for vegetation habitats inland evolution this will become the main barrier, for example, wetland is destructed and drained due to reclamation of human beings, as shown in the second Figure.

4.7.2.3 Salinity, CO_2 and Other Factors

Salinity increases as the level of sea arise because the water move farther inland and expose the communities of vegetation to the stress of salinity. The vegetation direction is mainly controlled by relative elevation and habitat area change by the soil salinity succession. The area near the tidal erosion or low-lying area near to the sea have good ratio of salt-tolerant plants. The decrease in soil salinity occurs as we move from low to high-tidal flat and diversity in the salinity tolerance of plants confirms that, because the plants on high-tidal flat will be less salinity tolerant. As elevation decrease from high to low, the depth of ground water increases in the result of water's capillary action to reach surface and affect the level of salinity. Due to the observed climatic changes, CO_2 concentration increases in the atmosphere. The concentration of dissolved inorganic carbon in water also increases as a result of increase of carbon dioxide concentration in atmosphere. Communities of vegetation can be affected by the tropical storms which are increased in climate change result. From little increase in salinity, the flooding was very important in the survival and growth of most species but severe increase in the salinity is very harmful to all kind of vegetation communities tested flooding extent regardless.

4.7.3 Vegetation Analysis in Various Factors Response

If rise in sea level continuously stable then in coming next few decades the land area will be converted into open water from freshwater marsh and coastal salt on the large scale and change in the habitat, structure and movement of vegetation will occur. In various factors response, experiments performed in various fields and labs on vegetation evaluated the great succession.

Various greenhouse experiments shows that the plant cannot grow well in the highly saline soil but can tolerate the salinity little bit because of physiological tolerance as plants are known for their competition for nutrients and water. In moderate to high saline environment, high salinity tolerant vegetation occupy leading occurrence but will be weak competitor at low salinity as compared to that of low tolerant community. In response to climate change, monitoring for long term can help in the structure and dynamics of forest which suggest that the structure of forest dynamic quantification and climate change response through long term monitoring suggest that:

1. The seedling population in the forests of bottom land significantly alter through the climate change with increase in drought and sapling layer recruitment, and influence ultimately over the structure canopy of story.
2. shade-intolerant and early successional species may form due to the disturbance bounded with the storms and floods and
3. Due to the damage of hurricanes and strong storms, the mangrove forest structural composition will disturb and the mangrove forest will become shrink in size.

In the laboratory, the higher concentration were measured of dissolved carbon dioxide in the photosynthetic activity of some vegetation of submerged freshwater species like Hydrilla, coontail and wild celery and some seagrasses like shoal grass. Increase in the photosynthetic activities is observed in all four species in the higher concentration of carbon dioxide response but the growth of plant tissues is not observed by the increased carbon dioxide ratio. C-N increased ratio in the tissues of plants results in the low quality forage for winter waterfowl as they used it as nutrient source.

4.8 Changes in Structure of Vegetation Community

Climate change cause change in the community's structure internally like erosion of coast line, stress of salinity and storm surge. The increased number of landscape patches of vegetation showed discrete distribution E.g., from the fresh-water insufficiency, in vegetation transformation process to saline-marsh from wet unripe vegetation, in landscape and disorder two types of vegetation disrupted was molted. Between different types of communities, structure trend of community isn't fragmented but distribution is tend to be concentrated which form large plaque For example, where the artificial crop and natural coastal vegetation are connected, the artificial killing wetland vegetation and other crops eroded except cash crops. In natural existing population of wetland vegetation the variation exist on the basis of salt-tolerance, so the new varieties can be developed that have tolerance against the salinity and the efforts for those communities that are killed by the saltwater intrusion can be done by the reforestation. Thus, the artificial cultivated plants with the tolerance of salinity, drought and other stress tolerant characters can be expanded rapidly. Additionally, the opportunities for the other exotic species can be developed by enhancing the invasion rate into natural stands.

4.9 Changes of Vegetation Succession Direction

Coastal wetland's natural development process is disrupted due to the climate change which is causing the unreasonable or reverse succession of vegetation communities of wetland which speed up the degradation of the coastal wetland, as shown in the Fig. 4.5. Due to the lack of freshwater, the vegetation of wetland wet-unripe is degraded into saline-marsh vegetation, the decrease in the elevation of surface is the result of low accumulation rate than sea level rise. By the shoreline erosion, the inter tidal community of sparse vegetation is retreated, opposite succession in the wetland's beach bare-light. By the rise in sea level, the blockage of land movement of the vegetation of wetland is caused by the economic crops that are planted by artificial reclamation. In the result of Irrational tillage, the ammonia nitrogen content and organic matter decreased, through which the vegetation community's suuccession will occur or it will facilitate the harmfull species invasion.

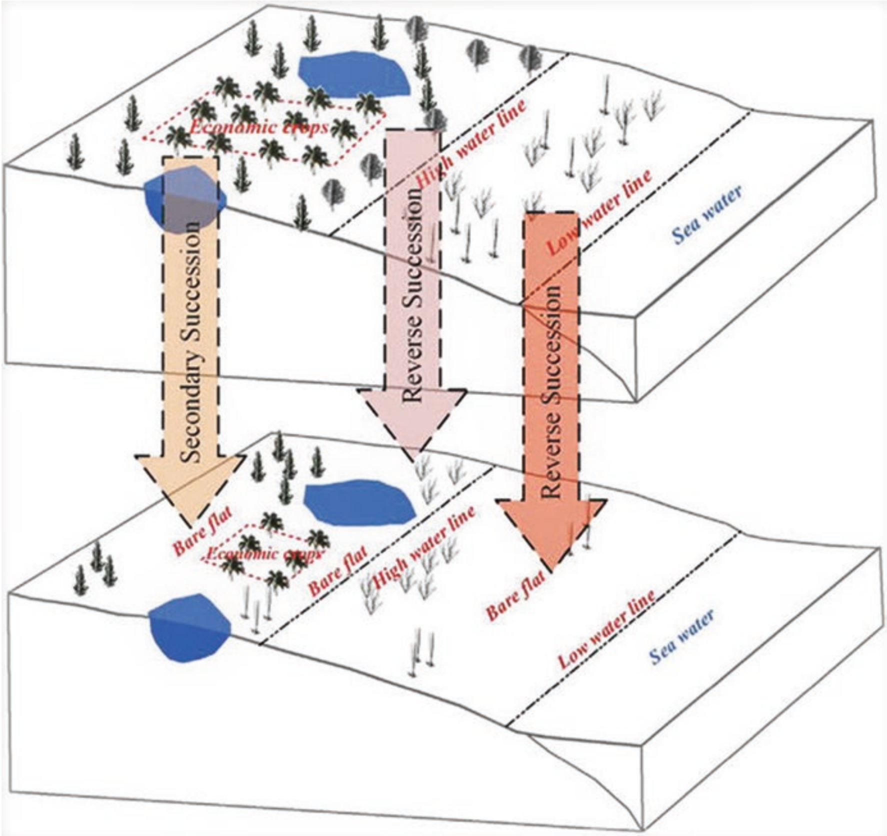


Fig. 4.5 The sketch map of direction of vegetation succession change

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Chapter 5
Climate Change Forecasting and Modeling for the Year of 2050

Bayram Ali Yerlikaya, Seher Ömezli, and Nazlıcan Aydoğan

Abstract Climate change as a result of global warming is a concern all over the world. Scientists have tried to understand the place in the future scenario of climate change by developing different forecasting systems to investigate these concerns. There are many forecasting systems have been developed to plan and minimize the negative consequences of climate change in various fields in our lives. Agriculture is a production platform and severely affected by parameters result from climate change such as drought, flooding, heat and cold stresses. Climate Forecast and agriculture is an interdisciplinary research program based on advances in various fields. It is predicted that the temperature, which is expected to increase by 2 °C by 2050, will cause close to 50 million people to experience hunger risk due to agricultural effects. This concern in agriculture has demonstrated the need for maximum use of agricultural resources and areas. Many models have been developed for these purposes, which are a simplified description of a system through a computer adapted representation that allows us to conduct virtual experiments. In this chapter, there is brief discussion of climate change for the year of 2050 through the world and information about forecasting and modelling systems on agriculture.

Keywords Climate change · Modelling · Forecasting system · Agriculture

5.1 Overview

Climate change is defined as alteration on climate due to anthropogenic (human-induced) activities that directly or indirectly alter the composition of the atmosphere, in addition to the natural variability of the climate observed in a comparable period. Human activities, such as fossil fuel use, deforestation, wrong land use, agricultural activities and industrial processes, cause climate change by changing the composition of the atmosphere. Consumption of fossil fuels, together with other

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_5

human activities, has been caused increasing the atmospheric concentrations by creating a greenhouse effects by gases. In global temperature estimations on agriculture, it is predicted that the temperature, which is expected to increase by 2 °C by 2050, will cause close to 50 million people to experience hunger risk due to agricultural effects (Watkiss 2005; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Agriculture is one of the most valuable field among economic sectors due to the nature of the impacts of climate change. Production process include the direct use of weather inputs (temperature, solar radiation and rainfall). Climate change alter the weather and thus has a direct, biophysical effect on agricultural productivity. How can science help to get over all complexities arising from environmental situations? On one sense, continuous explosion in the amount of published information and data gives opportunities from every field of science. Due to the major effects of climate change such as drought, heat, flooding and freezing, there have been essential needs on agricultural forecast systems. Additionally, scientific examination of an agricultural ecosystem requires a system model and interactions of components that take into account agricultural production, natural resources, environmental and human factors. The model, once operated by the simulation mechanism, contains a set of instructions, rules, equality or constraints based on input and output behavior. Therefore, models are required to understand and estimate overall agroecosystem performance for specific purposes (Wallach et al. 2018). In conclusion, climate change by the year of 2050 will cause severe effects on every branch of our lives, however, we have huge data about forecast and modelling systems that enable us to predict the adverse conditions and their possible solutions by the help of simulations. Thus, understanding and improvement in forecast and modelling systems will enable us the precious way to save our future generations.

5.2 Climate Change and Its Effects

Climate change is defined as alteration on climate due to anthropogenic (human-induced) activities that directly or indirectly alter the composition of the atmosphere, in addition to the natural variability of the climate observed in a comparable period according to the United Nations Framework Convention on Climate Change (UNFCCC) (BMİDÇS 1992).

Human activities, such as fossil fuel use, deforestation, wrong land use, agricultural activities and industrial processes, cause climate change by changing the composition of the atmosphere. Consumption of fossil fuels, together with other human activities, has been caused increasing the atmospheric concentrations by creating a greenhouse effects by gases that are naturally present in the composition of the atmosphere and make the world a livable place. As the greenhouse gases in the atmosphere are permeable to the incoming solar radiation, but are much less permeable to the long-wave (infrared) ground radiation emitted, this natural process which makes the world warm up more than expected and regulates the heat balance is called “Greenhouse Effect” (Türkeş 2001) (Fig. 5.1).

In global temperature estimations on agriculture (Fig. 5.1), developing countries will be adversely affected by the increasing temperature rise. However, the European Union countries and the USA will be positively affected by the temperature rise up to 2 ° C. However, it is estimated that the average temperature increases exceeding 2 °C will have negative consequences for the European Union countries. In addition, a temperature increase of 2.5 °C by 2080 will cause hunger risk on close to 50 million people (Watkiss 2005). Due to rising temperatures, areas where certain crops are grown will change northward and higher. This will adversely affect developing countries in the tropics. African and Central American countries in the tropics, who earn most of their income from exports of agricultural products, will be adversely affected by global warming. For example, rice production in the Philippines is expected to be adversely affected by the increasing temperature rise. In a case where the temperature rise is 1 °C, 10% reduction in rice production is expected. Countries in the northern latitudes, such as Canada and Russia, will have

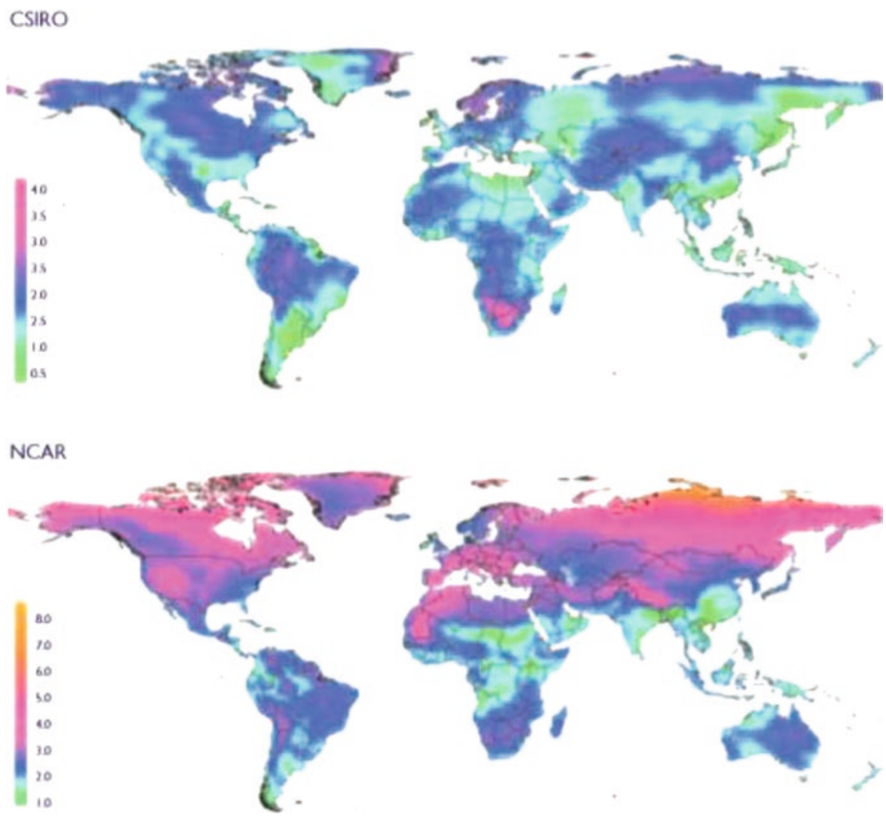

Fig. 5.1 Shows the change in average maximum temperature between 2000 and 2050 for the CSIRO and NCAR scenarios (IFPRI 2009)

expanding agricultural areas due to global warming. However, even if the climate in these countries offers favorable conditions, there are some doubts that soil conditions may be suitable for intensive agriculture (UNEP 2006). Changes in the rainfall will have an impact on agriculture. In this respect, the southern latitudes, which are mostly developing countries, will be at a disadvantage compared to the northern latitudes. Increased carbon dioxide concentration in the atmosphere is expected to contribute positively to the growth of certain agricultural products. Plants classified as C3-class, including rice and wheat (plants with high carbon dioxide concentration and low temperature, low ability to use light intensity, temperate zone plants), will be positively affected by the increased amount of carbon dioxide. In addition, C4-class plants such as corn, sugar cane (plants with low carbon dioxide concentration, high temperature and lower water requirements, seasonal drought-resistant organic compounds that initially contain 4 carbon atoms, high ability to use light intensity), increased carbon dioxide amount will be negatively affected. These products are grown mainly in African and Latin American countries.

Assuming no CO2 fertilizer effect in developing countries, there is a decrease in agricultural products compared to 2000 in 2050. In these countries, the highest crop losses are expected to be in rice and wheat grown by irrigation systems. On the other hand, it is seen that developed countries are less affected by these effects of climate change on average compared to developing countries and even climate change has a positive effect on the quantity of some agricultural products in developed countries (IFPRI 2009).

While making these projections depending on climate change scenarios, the situations of Central and Far East Asian countries including China were taken into consideration and countries with tropical temperate climate were evaluated. Accordingly, South East Asian countries such as Indonesia, Philippines, Singapore, Vietnam, Cambodia and Thailand are expected to experience severe losses of agricultural products due to climate change, and decrease in the productivity and product quality of all product groups in these countries is expected (IFPRI 2009).

On the other hand, the CO2 fertilizer effect slows down product reductions in some regions and increases the amount of products in some products compared to 2000. Nevertheless, there may be decreases in the production amount of corn grown with rain water and wheat grown with irrigation system/rain water. In Sub-Saharan Africa, the situation is more complex. As a matter of fact, there may be small ups and downs in the production of rain-growing corn; the most negative effect is observed in the amount of wheat grown by rain. Lastly, the effects of climate change in Latin America and the Caribbean cause some product increase in some products, but some decrease in the amount of product in some regions. Since the occupancy rate of the watersheds of the countries depends on the amount of precipitation, climate change is expected to have a direct impact on the watersheds and aquifers. As a matter of fact, in both climate scenarios (NCAR and CSIRO), they concluded that climate change will reduce the amount of precipitation falling on the earth. Changes in the amount of precipitation may increase the need for agricultural products to water due to the increasing temperatures and climate change. A small increase in the water consumption rate is expected to create great stresses on crops where irrigation is made (IFPRI 2009).

Agriculture both promotes the climate change and can be affected by climate change. The EU needs to decrease greenhouse gas emissions from agriculture and adapt the food production system to overcome effects of climate change. However, climate change is just one of many oppression on agriculture. Encounter with increasing global demand and rivalry for resources.

Agricultural production is heavily dependent on air, climate and water availability and is severely affected by weather and climate disasters. The occurrence of rain and natural disasters such like drought and flood can cause crop degradation, famine, food-insecurity, loss of property and lives and negative national economic growth. Therefore, the use of various traditional indicators in order to estimate seasonal climate behaviour is major key factor that enable agricultural communities to cope with climate variability.

Since we live in dynamic society where economic conditions and consequently price and relations among prices are constantly changing, our decisions and business decisions are largely based on forecasts. An forecast is an expression of what can be expected based on current situations and observations interpreted in light of previous experiences; and the basis for deciding what action to take to achieve the desired result. A scientific prediction is an estimate based on a discovered systematic order of normal experience.

It is likely that several avenues will improve the quality of forecasts of the agricultural impacts of climate change over the next five to ten years. First, dynamically combined crop models in climate models is going to promote a refined two-way interaction among agricultural and atmosphere land use. Secondly, remote-sensing and increase of spatial environmental databases supplies significant opportunities to increase the use and improve the quality and tenacity of climate based crop forecasts. Finally, climate-based crop estimates will benefit every branch of agricultural community based on weather within climate.

5.3 Agricultural Forecasting

Climate Forecast and Agriculture is an interdisciplinary research program based on advances in various fields, particularly in climate forecasting science, to reduce large-area climate forecasts for local applications and to improve alternative scenarios for the integration into operational crop models in order to minimize the effects of climate risks and maximize benefit for agricultural communities.

The major weather variables for crop estimation are precipitation, solar radiation and temperature, humidity and wind speed also play a role. Doblas-Reyes et al. (2006) reported that seasonal climate forecasts can provide insight into future climate development in seasonal timelines, as the slowly evolving variability in the oceans significantly affects changes in weather statistics. The climate forecasting community can now offer an end-to-end multi-scale (in space and over time) integrated forecasting system that provides skilled, useful estimates of variables with socio-economic interest.

How can science help to get over all complexities arising from environmental situations? On one sense, continuous explosion in the amount of published information and data gives opportunities from every field of science. On the other sense, the problem of handle all this information and supporting data becomes severe difficulties and causes information overload. The continuous knowledge explosion is promoting the important recognition of interconnectedness of what should have been applied earlier as independent process and components. These kind of interactions between components may get major effects on responses of system, thus overall system by studying components in isolation is not sufficient to make conclusions (Hieronymi 2013). These interactions go beyond the limits of traditional discipline. Although there is a strong emphasis on disciplinary science that causes a better understanding of the components and individual processes, system science is also increasingly emphasized.

Scientific examination of an agricultural ecosystem requires a system model and interactions of components that take into account agricultural production, natural resources, environmental and human factors. Therefore, models are required to understand and estimate overall agroecosystem performance for specific purposes. Data is needed to improve, estimate, and run models so that when a system is examined, inferences about the actual system can be simulated by model-based "experiments. If we need to list what these data are; crop yield, climate demands of the relevant crop and anticipation of possible risks, market characteristics and consumer requests of the related crop, etc. The development of integrated model-based prediction that will predict the future with all of these data at the same time is of paramount importance, and interest and demand have also increased in the near future.

Systems science, real world consisting of components defined by the expert "systems" to investigate. These components interact with each other and their environment in order to designate overall system behavior (Wallach et al. 2018). These interacting components are affected by an external environment that can affect the behavior of system components, but the environment itself cannot be exposed to changes that occur within the system boundary. Even though systems are small abstraction of the real world defined for specific targets, they are very useful in science and engineering in each branch of fields, consist of agriculture. An agricultural system or agricultural ecosystem is, as a general objective, a collection of components that produce crops and animal husbandry to produce food, fiber and energy from the world's natural resources. Such systems can also result in undesirable effects on the environment.

5.3.1 Forecasting Systems Developed in Last Decade

Due to the major effects of climate change such as drought, heat, flooding and freezing, there have been essential needs on agricultural forecast systems. In history, there are several model systems have been created for combat ability on climate change such as autoregressive integrated moving average (ARIMA), regression analysis, Markov chain, fuzzy logic (FL), different hybrid models, artificial neural network (ANN) and support vector regression (SVR) model systems (Han et al. 2010; Ozger et al. 2011; Belayneh et al. 2014; Masinde 2014; Stagge et al. 2015; Taormina et al. 2015; Belayneh et al. 2016; Sun et al. 2017; Ghorbani et al. 2018; Moazenzadeh et al. 2018).

Despite of the large variety data about forecasting models, researchers are still getting trouble to choose which model the best suited to their work. Therefore, the compilation of the model studies conducted in the last decade and briefly analysis of the pros and cons of the different models are definitely useful for the readers.

Regression analysis is simple and direct and has low computational cost, although it is not essential for long-lead forecasting by the reason of the assumption of linearity and need huge number of versions are required to produce accurate predictions. Stochastic models has ability to suit well to linear data, and it is systematic study for estimation, identification and diagnostic check for model development. However, low ability to model data with nonlinear characteristics and complicated computations are the main disadvantages for stochastic model. Probabilistic models is enable to combat with complex distributions but computationally expensive. The advantages of artificial neural network are the enable of detection all possible interactions among predictors and making multiple training algorithm, even though it is expensive and prone to over-fitting. Fuzzy logic has capability to model imprecise information and rule the arbitrary complexities, but the increasing fuzzy rules make the model expensive. Support vector machine can prevent over-fitting and has different kernels available for different datasets. However, support vector machines is numerically expensive in verification stage. Hybrid models have ability to compare pros of different models, although it requires large informative data to understand multiple models. Dynamic modelling gives real time results good for monitoring and forecasting purposes, but good connections is required among input and forecast system (Fung et al. 2019).

As a result, there are many criteria that affect the performance and accuracy of forecasting models. Appropriate inputs with appropriate time scales and appropriate timeframes are key factors for accurate estimations. The literature are also showing that the use of pre-treatment techniques give advantages to improve the accuracy of the models.

5.4 Modeling and Its History

Modeling is to create a structure that captures the interesting or noteworthy features and processes of the research topic. The model is simplified description of a system through a computer adapted representation that allows us to conduct virtual experiments on the behavior of a system. A system model is an abstract expression of its reality, with the exception of some details of its environment. The model, once operated by the simulation mechanism, contains a set of instructions, rules, equality or constraints based on input and output behavior. Many computer models have been developed for agricultural production systems. The models designed based on their specific purpose and in terms of the modeling and simulation approach on which they are based are quite different.

The history of agricultural system modeling is mainly based on the need of scientists from different branches to use models for different purposes. The first agricultural modeling was conducted by Earl Heady and his students on farm scale to assess the benefits of rural development on economic factors (Heady 1957). Following these early modeling studies in the 1950s, in 2012 Dent provided a book describing economic and biological contents and models of the agricultural system as an important resource. Shortly after agricultural economists began to model farm systems, a system called the International Biological Program (IBP) was created to help develop various ecological models that would also work in animal husbandry (Van Dyne and Anway 1976).

Later in the 1960s, physicists from Wageningen University made major contributions to the advancement of agricultural modeling within biological and physical principles. Another pioneer is W.G.Duncan, a chemical engineer who contributed to science with his publications on modeling of canopy photosynthesis. Even in the later years of his PhD, he began working on the first crop-specific simulation model especially for corn and maize. Integrated Pest Management has begun to arise with the study of diseases and pests on plantation in Malaysia (Duncan et al. 1967). The studies initiated especially by the pioneers in the modeling continued its development over the years. Wageningen University has taken great steps to reach the most widely used modeling techniques by educating many experts in agricultural modeling. In the 1990s, there has been an increase in modeling studies on the understanding of the effects of climate change on crops and economic aspects on a global scale. For this purpose, modeling studies have become widespread in order to understand the effects of greenhouse gas and carbon dynamics as well as economic modeling (IPPC 1990).

From the late 1990s to 2010, many individuals and seed companies interested in modeling have made great efforts to adapt ecophysiological effects to plant breeding with the help of modeling (White and Hoogenboom 1996). Modeling studies from 2006 to the present have focused on climate forecasts in the future. In particular, modeling studies continued on the investigation of the interaction of carbon dioxide effect with temperature and other factors important for plant growth (Long et al. 2006). With the increasing importance given to the issue, after 2010, some private companies formed their own teams for modeling and some of them continued to work with public-private partnership.

5.4.1 Types and Brief Descriptions of Modelling Systems

There are several models have been created based on the characteristics of the systems to be examined and research objectives. Oteng Darko et al. (2013) have reported several model systems. Empirical model is a direct definition of the obtained or collected data expressed by regression equations. Regression equations can be used for one or more factors. The data is obtained, the equation is established and the desired result yield is easily calculated. For example, determining the relationship between fertilizer application and final yield. Other model system is mechanistic model which observed the results in the lowest level. An example would be to evaluate at the cell level. With the help of these models, it is provided to respond to the short process by imitation of the physical, biological or chemical process of interest. Such systems are generally divided into parts according to their operations. Thus, modeling starts experimentally and evaluations are continued by adding variables. Based on static and dynamic models, time is not accepted as a variable, whereas in the dynamic model, time is used as an important and indispensable variable while the last data to be obtained in the static model is formed over time. Simulation models is such model systems which are designed to mimic a system that actually exists naturally; they are easily adaptable to changes in weather and soil conditions. It is necessary to have a lot of inputs in this model type to obtain more clear and easy information. In this way, management methods can be obtained inexpensively, especially on the subject of interest. Additional to that report, Brockington (1979) has reported a model, deterministic model, is a kind of model commonly used in the evaluation of quantities such as yield without any variance. However, such data is also often observed in variance, this heterogeneity is something that is biologically inherent to agricultural systems. In spite of these intrinsic changes, although the deterministic model is still quite usable, the accuracy of the model decreases if the changes increase.

One of the other key subject is the mechanism of simulation and modeling. While, modeling is a kind of exhibition of a model that consist of construction and working similar to real system, which provide analyze predict the changes to system, system simulation is a study of a model in terms of space or time that provide analyze the performance of an available or a offered system. Cros et al. (2003) have reported several simulation systems. Spreadsheet simulation refers to the use of a spreadsheet as a platform for representing simulation models and performing simulation experiments. Spreadsheet simulation is often used for agricultural production system applications where logical relationships between studies variables are established (ration analysis) and can be defined by simple static models that are mathematically represented. Secondly, continuous system approach expresses continuous state variables and time with systems of differential equations. In other words, the rate of change of state variables is defined by derivative functions. Additionally, discrete time systems assume a graded mode of operation. The dynamics of the system are represented by differential equations or transfer functions, which generally explain how to update state variables based on the state in the previous time step or inputs (influencing factors). The simulation mechanism is based on one-step iterative algorithms. They jump from one simulation step to another and calculate the status after the current status and inputs. All model variables are scanned at each step. In the discrete-event system approach, the transition functions specify local changes, similar to the modeling used for discrete-time systems in modeling the dynamic behavior of the system. In addition, this approach is based on identifying events that cause transitions when they occur. The most important difference with discrete time systems is the event processing mechanism. This mechanism allows you to jump from one point to another when the time comes (when the event occurs). It only scans the time points and variables related to the current event. If the event does not occur during the operating time, the status change will not occur. The simulation clock depends on the event. The discrete event simulation runs by reading the list of events sorted by their scheduled times. Events are taken from this list and processed in sequence, and relational operations that produce state transitions are executed. According to the results of the transaction, new events can be planned and put on the list or the old ones can be deactivated or discarded. Events can be caused by environmental conditions that are not under the control of the system itself.

LINGRA is a crop growth model enhanced by the former DLO-Winand Staring Centre (SC-DLO) together with the former Research Institute for Agrobiology and Soil Fertility (AB-DLO), both placed in Wageningen and now piece of ALTERRA, The Netherlands.

The GRASSLAND GROWTH MODEL – LINGRA (LINTUL Grassland) was developed to foresee accretion and progress of perennial rye grass across the member states of the EC at the level of potential production and water restricted production. The model is on the basis of the LINTUL (Light Interception and Utilisation simulator) conceptions as offered by Spitters (Bouman et al. 1996). The main basis of this concept is that crop growth is proportionate to the quantity of light intercepted by canopy (Bouman et al. 1996).

$$\text{Yield equation of LINGRA;} \int_{t=1}^{n} ft * PARt * Et * HI$$

**ft*: fraction of PAR intercepted by the leaves or foliages
**PARt*: active radiation of photosynthesis
**Et*: utilization of light efficiency during dry matter transformation
**HI*: dynamic grass specific fractioning

Wheat, rice, corn, soybeans have a very important place in human nutrition. Over time, global temperature rise will be inevitable. It is very important to evaluate the effects of temperature rise on these nutrients, which are important for human calorie intake. However, different studies have yielded different results. Zhao et al. (2017) used four analytical methods to investigate the effect of temperature on these products and compiled the results. These analytical methods are global grid based, local point based models, statistical regressions and field warming experiments. According to the results obtained in this study, it has been found that temperature increase has negative effects on these products and the results obtained from different methods were obtained in a similar manner. If the plant is not genetically developed as a result of every 1 degree increase in average temperature as a result of climate change, average global yield will decrease by 6% in wheat, 3.2% in rice, 7.4% in corn, and 3.1% in soybeans. Apart from the main crops, some positive results were also obtained. Thus, the reliability of modeling of multi-method analyzes was provided and the adaptation studies specific to the region or crop were initiated in order to ensure future food safety.

Agricultural production climate change and yield estimates are determined by the establishment of climate change scenarios or by statistical modeling of climate change forecasts from year to year. Many factors in agriculture are affected by climate change, and the number of crops per seeding area and the season also affects yields. In 2016, in Brazil, which is a very important agricultural region, the response of crop area and product frequency to climate change and how crop yields change as a result were modeled (Cohn et al. 2016). In this modeling, climate change resulted in approximately 70% frequency and area changes. Losses in hot and wet areas when an association is made; gains were obtained in cold and dry regions. It is not right to look directly at efficiency in climate change. In order to minimize these effects, it is necessary to consider not only the yield decreases but also the frequency of the area and crop.

Due to the limited water resources in the world, agricultural water use efficiency should be increased. Crop simulation models play an important role in assessing the change in water use and yield and in developing strategies for improving water use efficiency. Many agricultural models already exist, but the use of the model becomes difficult due to the limit of access to the model source code. Together with the study conducted by Foster et al. (2017), An open-source version of the model FAO AquaCrop, which simulates product production based on the amount of water, can be used in multiple languages and operating systems. Parallel application support can be used with this model and provides convenience in large geographical frameworks.

In conclusion, the need to predict the effects of climate change on agricultural production is an essential element in the development and analysis of scenarios that affect farmers' income and food safety. Owing to both the need to address the impact of climate change and the interest in increasing the ability to supply predictions globally, there has been a change in the type of model required to predict the amount of yield loss requiring models with broader workableness. Modelers overcome the scarcity of reference data and the need to develop the robustness and operability of modelling systems under these conditions in order to meet both requirements. We believe that agricultural modeling and forecasting systems provide a critical opportunity to overcome these obstacles, and we also believe, therefore, a vital need to develop modeling and forecasting capabilities to address all challenges based on climate change by 2050.

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Chapter 6
Effects of Climate Change on Irrigation Water Quality

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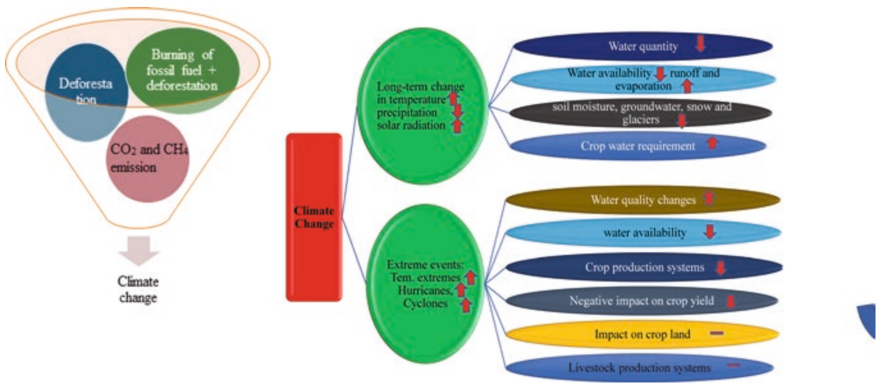
Graphical Abstract



Abstract Irrigation water quality is increasingly vulnerable to the climate change. Factors responsible for the climate change like CO_2 emission, CH_4 emission, industrialization, increasing population, and anthropogenic activates impacting water quality by the addition of heavy metals, pesticides, organic pollutants and others sedimentation. Climatic conditions like precipitation, temperature, floods, droughts impacting irrigation water quality. Quality parameters of water like micronutrients, pathogen, pH, dissolved oxygen is directly influenced by climatic condition, like rainfall, temperature, floods, and drought. Drought and floods and increasing tem-

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_6

perature are projected to negatively impact water quality. Quality and availability of water is vulnerable to change in rainfall patterns. Flood increase water pollution by deteriorating ground and surface water resources. Floods speed up runoff in urban region and bring huge toxic pollutants into the freshwater resources and deteriorate its quality. Large proportion of industrial contaminants are bringing to the rivers which contaminate irrigation water quality and make unfit for use. High proportion of heavy metal like lead, Cd etc. contaminate irrigation water quality and as results affect crop growth. Quality of fresh water is also affected by drought because of less availability of water to dilute the concentration of contaminates in the waters. In draught condition people are compelled to use that contaminated water for self-use and for their crops and animals which leads to several disease in their plants and animals. The practice of using clean water for both drinking and irrigation is necessary for the health life of inhabitant of country. Rainfall also affect irrigation water quality. During the season of monsoon rainfall, the rainfall deteriorates water quality because of the addition of organic pollutants, pathogens, and pollutants mixing with irrigation and drinking water resources during the season of monsoon rainfall. Higher rainfall transports more contaminants from one area into another area and degrade the water quality. In case of low rainfall condition, availability of water is low to dilute contaminated water resources. Water quality are also decrease with increase in temperature because of low discharge, stability of temperature, higher sedimentation of phosphorus and other nutrients. Increase in temperature with low discharge leads to increase growth of microorganism which deteriorate water quality. Increase in water temperature affecting biochemical processes occurring in water reservoirs. Global warming can influence concentration of oxygen in water reservoir. Increase in temperature will negatively affected water quality.

Keywords Irrigation- · Water quality- · Climate change

6.1 Introduction

Temperature and precipitation are the most important climate variables and essential inputs to agriculture production (Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Availability of reliable and safe water supply is most important concern for the Pakistani people. In Pakistan

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person water availability is low and decreasing with time, it is expected that Pakistan classified as water scarce country in the future. This condition has drastically impact most of the Pakistani people lives who be contingent on irrigated agriculture for their food and feed. Increase in temperature increase the rate of evaporation, rising seas as result greater saltwater addition in coastal areas. Increasing the rate of glacial melting increase the probability of flood and intensive rainfall and change in monsoon pattern are the most potential impacts of change in climate on hydrologic resources in Pakistan. As result of climate change, it is expected to negatively affect agriculture, health (WHO 2015), energy, municipal and domestic supplies of water. Pakistani agriculture system is closely linked with water availability in Indus River and its tributaries which provide for the irrigation system of Indus basin. In Pakistan more than 90% of agriculture production is generated by irrigation system. Largest livelihood sources of Pakistani people is agriculture and most of the rural areas are depended on agriculture produces (Maqbool and Bashir 2009). In agriculture sector water demand is projected to be high than in other sectors, to fulfil the increasing food demand of the increasing population (Amir and Habib 2015). Change in climate exerted additional pressure on this already challenged water system, agriculture sector as perhaps the most vulnerable sector to climate change. Agriculture sector is expected to be more affected by increase in mean annual and seasonal temperature and change in rainfall pattern, and extreme floods and drought weather events. Particularly impact of change in climate on water flows in Indus basin for irrigation purposes.

6.2 Irrigation water in Pakistan

In Pakistan agriculture production closely related to the water resources availability especially the water amount flowing in river Indus basin (GOP 2013). Dependency of Pakistani agriculture on Indus Basin Rivers is the fact that out of 26 Mha of Pakistani agriculture land, about 90% of the production is generated from the 18 Mha of irrigated areas (Yu et al. 2013). Irrigation system in Pakistan is composed of river Indus and its tributaries. It was recognized world largest wide system of irrigation with a length of 58,000 km.

Agriculture is chief user of freshwater world widely, which defend on continuous supply of irrigation water and rainfall. Current usage of agriculture is more than 70% of the fresh water. Higher rate of evapotranspiration/evaporation rates will considerably increase demand for irrigation water in some regions (IPCC 2007). Rainfed agriculture yield are more vulnerable to the seasonal variability in rainfall and expected to decline by 59% in some developing countries by as early as 2020. Extreme weather events in the form of droughts and floods are previously triggering major distractions and losses in system of agricultural production, predominantly where no adaptation resolutions are in place to alleviate the hazards. Moreover, millions of people relay for their agriculture water on melting of glacier and snow, it is recognized that fast melting of glacier, increasing the floods risk in the short term and in long term presenting water scarcity.

Melting of snow in the range of Himalayan and Karakoram mountain along with rains of monsoon bring about 191MAF of water annually through Indus and its tributaries to Pakistan, which is mostly used for irrigation purposes. Despite the presences such flow and world most extensive system of irrigation and networks of canal Pakistan is classified as water stressed country. In Pakistan today water availability per capita I just over 1000 m^3 in comparisons of 5600 m^3 at independence time (LEAD Pakistan 2014). In part, this is because demand for water by the agriculture sector, particularly for irrigation, is expected to increase at a higher rate than all other sectors to meet the rising food production requirements of an increasing population. Irrigation water quality in Pakistan is poor as reported by Azizullah et al. (2011); Watto et al. (2006); Ahmad et al. (2015); Murtaza et al. (2008).

6.3 Water Availability and Climate Change

Along with the challenges of inadequate and ageing water infrastructure, increasing water demand, and poor management of the Indus River Irrigation System, climate change is projected to be an additional stressor on Pakistan's water resources. Changes in Pakistan's climate have already been observed, with mean annual temperatures reported as having risen by 0.6 °C over the course of the twentieth century. Several reports also state that there has been an observed overall trend of rising precipitation levels, particularly during the monsoon season, but patterns vary by region and season. Thus, while precipitation levels in the Upper Indus Basin have been increasing, they have been declining areas such as the western Baluchistan plateau and coastal areas. Changes in precipitation trends are more visible in the southern portion of Pakistan (Yu et al. 2013).

6.4 Agriculture and Climate Change Vulnerability

Among the different sectors agriculture is the most exposed sector to the risk of climate promoted by change in climate, such as increase annual mean temperature, uncertain monsoon rainfall, more runoff. Change in availability of water could change the crop sowing and harvesting in the coming 2–3 decades. Considerable decrease in crop yields could also result from elevated temperature, speeding up crop growth, and decreasing growth period and decrease productivity of crops (GOP 2012). Production of livestock is also susceptible to the risks of change in climate. Livestock along with poultry share half of the value shared by the sector of agriculture, to the GDP. Increase in temperature as result decreased milk and meat production and decrease capacity of reproduction. Moreover, change in climate also negatively affected fodder crops productivity, reducing palatability and nutritional quality of crops due to rising CO_2 level.

6.5 Water Quality and Climatic Change

Irrigation water quality is increasingly vulnerable to the climate change (Zhang et al. 2015a). Factors responsible for the climate change like urbanization, industrialization, increasing population, and anthropogenic activities impacting water quality by the addition of very metals, pesticides, organic pollutants and others sedimentation (Sadia et al. 2013). Climate condition like precipitation, temperature, floods, droughts impacting irrigation water quality (Pakistan Meteorological Department 2012; Whitehead et al. 2009; Yi et al. 2014). Quality parameter of water like micronutrients, pathogen, pH, dissolved oxygen is directly influenced by climatic condition, like rainfall, temperature, floods and drought. According to the IPCC, variation in extremes environmental events like drought and floods and increasing temperature are projected to impact quality of water and will increase pollution of water intensity (Bates et al. 2008). Quality and availability of water is vulnerable to change in rainfall patterns (Abbass 2009; Delpla et al. 2009; Hien et al. 2015; Hunter 2003; Khaliq 2008). Change in climate will increase glacier melting rate which s result affect the chemistry of water and runoff of rivers. Climate change affect both biological and chemical properties of water, decrease in availability of water will drastically affect quality of water indicators such as E. coli and faecal coliform (Liu and Chan 2015).

6.5.1 Floods

Flood increase water pollution by deteriorating ground and surface resources of water. Floods speed up runoff in urban region and bring huge toxic pollutant into the freshwater resources and deteriorate its quality (Saeed and Attaullah 2014). Large proportion of industrial contaminants are bringing to the rivers which contaminate irrigation water quality and make unfit for use. High proportion of heavy metal like lead, Cd etc., contaminate irrigation water quality and as results affect crop growth (Murtaza et al. 2008; Wattoo et al. 2006). Additionally, flood affected areas mostly experience shortage of fresh drinking water, as result people are compelled to use that contaminated water as result waterborne and other disease increase in that areas (Naseer and Jamali 2014).

6.5.2 Drought

Quality of fresh water is also affected by drought because of less availability of water to the concentration of contaminates in the waters. In draught condition people are compelled to use that contaminated water for self-use and for their crops and animals which leads to severs disease in plants and animals. The practice of using clean water for both drinking and irrigation is necessary for the health life of inhabitant of country.

6.5.3 Rainfall

Rainfall also affect irrigation water quality. During the season of monsoon rainfall, the rainfall deteriorates water quality because of the addition of organic pollutants, pathogens, pesticides and pollutants mixing with irrigation and drinking water resources during the season of monsoon rainfall (Tariq et al. 2007). Higher rainfall transports more contaminants from one area into another area and deteriorate water quality. In case of low rainfall condition, availability of water is low to dilute contaminated water resources (Mirza et al. 2007) (Guillaume and Rita 2009).

6.5.4 Temperature

Water quality are expected to decrease with increase in temperature because of low discharge, stability of temperature, higher sedimentation of phosphorus and other nutrients. Increase in temperature with low discharge leads to increase growth of microorganism which deteriorate water quality. Increase in water temperature affecting biochemical processes occurring in water reservoirs. Global warming can influence concentration of oxygen in water reservoir. Increase in temperature will negatively affected water quality. The influences of change in climate on resources of water (Fig. 6.1).

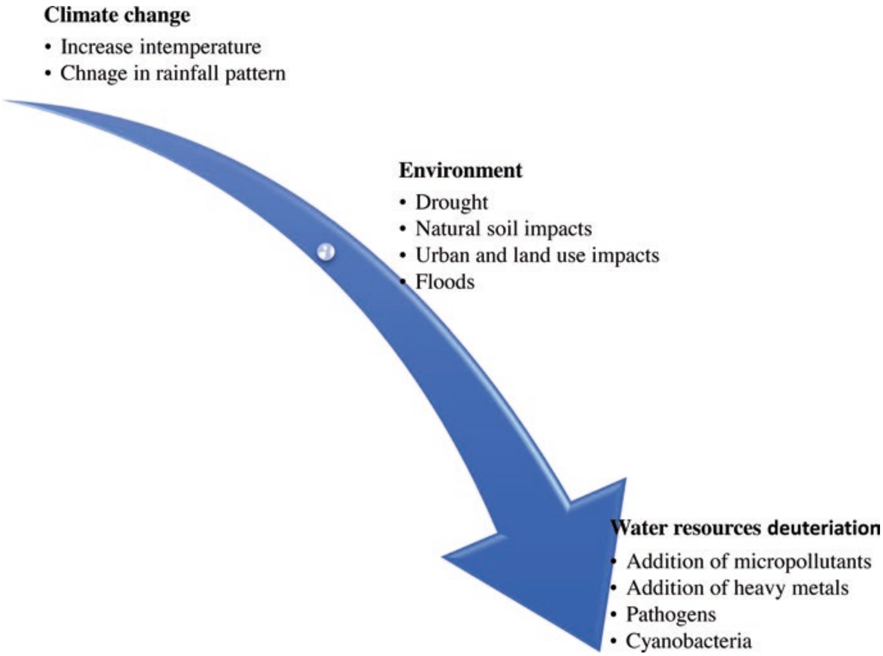

Fig. 6.1 The influences of change in climate on resources of water

Addition of heavy metals and pesticide deteriorate water quality (Ata et al. 2013; Jabeen et al. 2015). According to Zhang et al. (2015b) stated that climate change influences the water quality of river Indus and other resources of water in Himalayan region due to the melting of glacier which lead to water chemistry and water runoff. Saeed and Attaullah (2014) reported that floods occurrence negatively affecting water quality. They concluded that water quality is directly affected by floods and make them no more suitable for drinking and irrigation purpose.

6.6 Conclusion

- CO_2 emission, CH_4 emission, industrialization, increasing population, and anthropogenic activates impacting water quality by the addition of heavy metals, pesticides, organic pollutants and others sedimentation. Climatic conditions like precipitation, temperature, floods, and droughts impacting irrigation water quality.
- Quality parameters of water like micronutrients, pathogen, pH, dissolved oxygen is directly influenced by climatic condition, like rainfall, temperature, floods, and drought. Drought and floods and increasing temperature are projected to negatively impact water quality. Quality and availability of water is vulnerable to change in rainfall patterns.
- Flood increase water pollution by deteriorating ground and surface water resources. Floods speed up runoff in urban region and bring huge toxic pollutants into the freshwater resources and deteriorate its quality.
- Drought also effect quality of fresh water because of less availability of water to dilute the concentration of contaminates in the waters.
- Water quality are also decrease with increase in temperature because of low discharge, stability of temperature, higher sedimentation of phosphorus and other nutrients.
- Global warming can influence concentration of oxygen in water reservoir. Increase in temperature will negatively affected water quality.

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Chapter 7
Prospects of Biochar in Alkaline Soils to Mitigate Climate Change

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Abstract Climate change is one of the most threatening issues persisting on the planet earth; challenging the existence of life due to greenhouse gases emission including atmospheric carbon dioxide concentration. Additionally, unpredicted shift in climatic indicators may hinder the sustainability of life. It is, thus, imperative to combat these harsh climatic variations by controlling emission of greenhouse gases especially carbon dioxide. Soils serve as source and sink for greenhouse gases including carbon dioxide, methane and nitrous oxide. Therefore, the accurate quantification of storage and emission capacities are needed to obtain reliable global

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_7

budgets that are necessary for land-use management, global change and for climate research. The inhabitants of the developing countries have suffered and will suffer greatly from the consequences of climatic uncertainty as the rain patterns will observe a huge shift that will encourage the floods and water scarcity. To cope with the challenges of climatic changes and emission of greenhouse gases, effective and practical techniques are required for the storage within the soil. An efficient and cost-effective method for this purpose could be the pyrolysis of biomass in the absence or limited oxygen and controlled conditions of temperature and pressure to a carbon-rich compound called as biochar since biochar has been characterized as a stable and long-lasting soil amendment possessing a wide potential of increasing agricultural production, carbon sequestration, and environmental quality. Researchers have been explored and investigated its applications mostly in acidic soils but data regarding its potential benefits in alkaline soils is lacking. This chapter will provide an insight into latest scientific research of biochar as a viable option for combating climate change hazardous in alkaline arid soils. The characteristics of biochar responsible achieving these benefits will also be discussed. Additionally, modification techniques of biochar suiting alkaline soil will be the part of this chapter since the use of biochar as soil amendment is normally not recommended for alkaline soils due to its alkaline nature. However, as a cost-effective soil amendment, especially for climate change mitigation, needs detailed discussion to highlight all aspects of biochar could be exploited for alkaline soils being a carbon-rich product has potential to improve total organic carbon in soil along with its other agronomic uses for soil improvement in terms of soil CEC, pH, bulk density, water and nutrient holding capacity, microbial activity enhancer, remediation of polluted and degraded soil besides its carbon sequestration potential for mitigation of climate change.

Keywords Climate change · Biochar · Organic carbon · Alkaline soils

7.1 Introduction

Climate change has boomed due to anthropogenic activities and is becoming a major threat to human life (IPCC 2013). The environmentalists have established that the earth's lower atmosphere and oceans are warming sea level rising due to global warming and now it has been accepted globally as an undeniable reality and greatest challenge to cope in modern time (Bernstein et al. 2007). The patterns of rainfall would be shifted which will contribute to unadorned water scarcities or runoff. Furthermore, increasing trend of atmospheric temperatures will force change in crop growth pattern which may reduce crop yields in tropical areas by an increase in temperature to a predicted value of 1 to 2.5 °C by 2030. The entire world population would experience the health and life risks by food shortages and distribution of disease vectors (IPCC 2014a, b; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b).

The agro-ecosystems are both sources and sinks for greenhouse gases and their contributions in mitigating climate change depends on dual strategy (i) decreasing greenhouse gas emissions (ii) increasing sinks so that the net impact on global warming is less than at present. The emissions of carbon dioxide, methane and nitrous oxide occur due to various agricultural activities including land plowing, fertilization, and animal husbandry (Denman et al. 2007). Therefore, the reductions in emission of greenhouse gases can be obtained through decreasing the fast conversion of organic carbon to carbon dioxide and by better management of agricultural wastes to control the release of methane and nitrous oxide. Current sinks include carbon capture in crop biomass and soil organic matter. In addition, oxidation of atmospheric methane by soil bacteria also contributes in this respect. These sinks can be enhanced by increasing net primary productivity to capture more atmospheric carbon dioxide and by promoting more oxidation of methane by soils (Lehman et al. 2010). The entire problem of increase in global warming and greenhouse gases increases the atmospheric temperature ultimately. Among these gases; carbon dioxide, nitrous oxide, and methane are important.

Although many people typically attribute carbon dioxide emissions to energy production, there are other important contributing activities, such as transportation and agriculture. The most recent Intergovernmental Panel on Climate Change (IPCC) reported that the agriculture, forestry, and land-use sector was responsible for about one-quarter of global greenhouse gas emissions. Why have emissions from agriculture been increasing with time? There are two key contributors to increasing emissions. Firstly, a growing global population requires an overall higher food production. This increased requirement for food has led to both expansion of agricultural land and intensification of farming practices (IPCC 2014a, b). Agricultural land often expands into previously forested areas, and this process of deforestation releases carbon dioxide stored in trees and soils. These emissions are included in the accounting related to agriculture, forestry, and land use and it is estimated that up to 80% of deforestation is the result of agricultural expansion. Secondly, global economic growth has not only resulted in an increase in food demand but also in changes in dietary composition; that is, changes in what we eat. Economic growth is typically related to an increase in meat consumption. Livestock is an important source of greenhouse gas emissions, with variations between animal and chicken products (Tilman and Clark 2014) (Fig. 7.1).

Biochar is a carbon-rich product produced through thermochemical processing of biomass under an oxygen-deficient environment. It has been a hot topic of research in recent years due to its versatile role in soil biogeochemical processes. The most important ecological functions of biochar include acting as a long-term carbon sink for climate change mitigation (Bird et al. 2017). Moreover, biochar not only sequester carbon but, also equally important for reduction of greenhouse gases emission including ammonia and nitrous oxide as investigated by Woolf et al. (2010) that 12% per annum reduction in emission of carbon dioxide, methane and, nitrous oxide is possible with biochar when it was used for carbon sequestration into

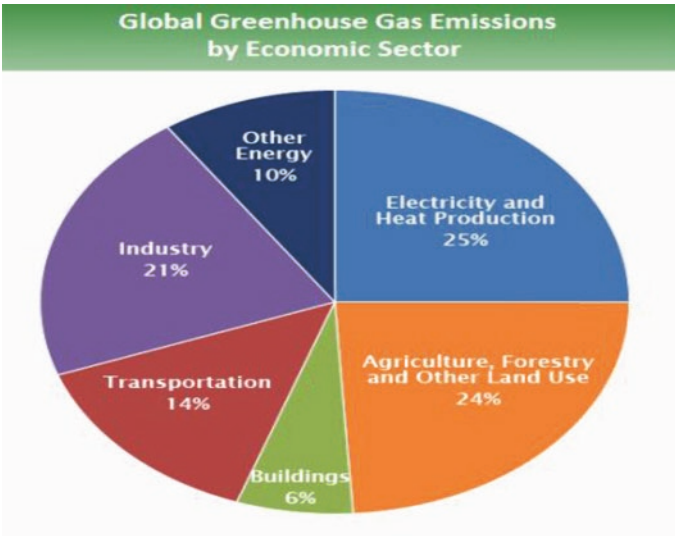

Fig. 7.1 Share of GHGs by different economic sectors. Source: IPCC (2014a, b)

soil. Recent researches further confirmed that biochar application to soil is very efficient in mitigating greenhouse gas emissions and climate change (Zhang et al. 2010). It has been proved that the addition of biochar is environmentally friendly and it has potential economic value in the better agricultural productivity by saving water quality and reduced emission of these greenhouse gases. The most significant feature of biochar is the carbon sequestration in soil for a very long period of time. Consequently, biochar is under greater attention of climate and policy analysts. So its technical and practical feasibility with targeted benefits to soil and climate must be considered thoroughly (Rasul et al. 2016).

It has been estimated that biochar systems can mitigate up to 1.8 Pg carbon, per year without endangering food security, habitat or soil conservation – a larger climate-change mitigation potential than using the same biomass for bioenergy (Woolf et al. 2010). From a global and policy perspective, the potentially negative impacts of biomass use on climate forcing must be considered. These include the effects of soot and trace gases that are emitted into the atmosphere during combustion. Airborne transport and deposition of soot has been implicated in the acceleration of polar ice melt, but conversely in facilitating cloud formation and 'global dimming'. Since, biomass burning accounts for 10% of global methane and 1% of nitrous oxide emissions. Although biochar production may contribute to these emissions but in long term till the major shift it would help in decreasing these emissions (Woolf 2008).

Most of the research conducted so far regarding potential benefits of biochar as soil amendment and climate change mitigating tool has been focused on acidic soils but biochar prospects in alkaline arid soils cannot be ignored since alkaline soils (pH > 7) are mostly situated in arid and semi-arid areas of world covering about

700 million hectares around the world (FAO 2002). These soils characterized by low organic carbon (Brady and Weil 2010), high soil pH, with deposition of calcium carbonate-containing loess materials, or developed from calcareous parent materials. These affect the microbial activity and soil microbial biomass causing changes in soil respiration, especially when the soil is dry (Mavi et al. 2012). In alkaline conditions, increase in soil organic carbon mineralization and bulk density is a common issue which reduces flocculation of aggregates and breaks down soil structure which also promotes soil erosion and degradation (Wong et al. 2008). Organic matter plays an important role in forming soil structure but common organic biomasses are prone to rapid mineralization in alkaline soils. Hence, biochar can play a crucial role in alkaline soils due to its recalcitrant nature and ability to limit greenhouse gases emission. A detailed discussion regarding benefits of biochar to mitigate climate change will be carried out in next heading of this chapter to reveal its significance for alkaline soils.

7.2 Prospects of Biochar to Mitigate Climate Change in Alkaline Soil

The idea of using biochar for carbon sequestration and climate change mitigation has earned wide popularity among the researchers during the recent time due to its versatile potential of excellent soil amendment and greenhouse mitigation strategy for sustainable environmental management (Paustian et al. 2016). The most vital capability of biochar is its recalcitrant and resistant nature against rapid mineralization compared to other organic amendments. Lehmann (2007) indicated that biochar has potential to retain carbon in host soils for hundreds to thousands of years as it can be proved from Terra Preta soils of the Amazonian region in Northern Brazil (Wang et al. 2016). It is still under debate that how biochar mitigates greenhouse gases emission. It could be conversion of agriculture and forestry wastes in biochar may minimize carbon dioxide and methane emissions compared to natural mineralization of original waste.

Biochar has potential to control emission of greenhouse gases through three primary pathways (i) bioenergy produced by pyrolysis may minimize greenhouse gases emission by converting biomass carbon into recalcitrant carbon, (ii) biochar can increase soil quality which may increase net productivity which ultimately reduces economic pressure to convert native lands to agricultural production, (iii) biochar applications may directly reduce GHG emissions from soils (Fidel et al. 2019). Several researchers have investigated that (1) biochar improves soil aeration and immobilization of available nitrogen in the soil, resulting in the suppression of denitrifier activities (2) increases soil pH and the relative abundance of the bacterial nitrous oxide reductase nosZ gene that reduces nitrous oxide to elemental nitrogen more efficiently (3) increases adsorption of organic compounds and microbial inhibiting compounds, such as ethylene (4) increases adsorption of nitrous oxide, nitric oxide and ammonia onto the biochar surface. But the extent of the reduction in emissions is, however, dependent on several factors such as biochar type, soil and environmental conditions (Borchard et al. 2019). Biochar may also reduce greenhouse gases emissions by influencing soil microbial community size (Zhang et al. 2014), composition (Lehmann et al. 2011) and by providing substrates to microbes (Singh et al. 2010) and water/oxygen. Additionally, biochar is believed to change soil redox conditions (Cayuela et al. 2014). Overall, most of studies reported that biochar reduces emissions (Case et al. 2015; Ameloot et al. 2016) however some also revealed contrary findings (Cheng et al. 2012; Wang et al. 2014).

Considering all above-stated information, it is important to understand potential benefits biochar in alkaline soils since most of biochars are commonly alkaline in nature (Jiang et al. 2012) which may contribute their liming effects to soils and alkaline soils already have alkaline soil pH. However, biochar pH generally ranges from acidic to alkaline (Chan and Xu 2009) but lower pH biochars are normally neglected. Biochar pH increases with increasing pyrolysis temperature as acidic functional groups are depleted at higher temperatures (Ippolito et al. 2016). But, biochars those are produced at low temperatures could be acidic (Zhang et al. 2017). Similar findings were reported by Hagner et al. (2016) who produced birch biochar at 300 °C and 375 °C having acidic pH 5.1 and 5.2, respectively while Novak et al. (2009) pyrolyzed Pecan shell at 350 °C and switch grass at 250 °C which has pH 5.9 and 5.4, respectively. Meager literature available in this respect shows that the lower pH produced at lower temperature could be acidic which initially increase plant-available nutrients in arid calcareous soils (Ippolito et al. 2016). Similarly, neutral biochars may also behave differently from normally available alkaline biochars in environmental processes after being added into soils.

Some recent studies have also revealed the modification of biochar for a specific purpose. In the next section we will discuss options of modification of biochar for its beneficial use in alkaline soils to achieve its potential benefits for mitigation of climate change.

7.3 Modification of Biochar for Alkaline Soils

In recent times research has been focused on the use of biochar in highly weathered soils but biochar use in less weathered temperate and arid systems is a relatively new concept. Soils under arid and semiarid climates are alkaline. Generally, increasing pyrolysis temperature increases nutrient content, specific surface area and pH of biochar (Kloss et al. 2012). Furthermore, increase in pyrolysis temperature will remove the acidic functional groups and causes biochar to become more basic (Ahmad et al. 2012) because higher pyrolysis temperature enhance minerals like potassium hydroxide, sodium hydroxide, and calcium and magnesium carbonate which ultimately results in rising pH of biochar (Cao and Harris 2010). So, the biochar is not suitable for alkaline soils generally. Beneficial use of biochar in alkaline soils is only possible when biochars are produced with lower pH. Thus, there is research gap to develop biochars for alkaline arid and semi-arid climatic regimes.

The inherent variability of biochars proposes that the biochars can be modified for specific situations. Biochars produced at low-temperature exhibit low pH and these could improve the environmental quality by reducing nutrient losses in calcareous soils (Ippolito et al. 2012). The addition of high levels of biochar adversely affected plant growth and there were no significant positive effects on growth and soil properties in calcareous soils. Addition of biochar increased soil pH and EC. It also increased the Proline content which created abiotic however biochar can be used as a soil amendment at application levels of less than 2.5% in alkaline soils (Mohawesh et al. 2018). Biochar can be modified by acid, alkali, oxidizing agents, metal ions, carbonaceous materials, steam, and gas purging. The selection of modification methods depends on the environmental application fields. The biochar has been used for soil remediation and amelioration, carbon sequestration, organic solid waste composting, decontamination of water and wastewater, catalyst and activator, electrode materials and electrode modifier (Wang and Wang 2019).

In order to obtain desirable biochar properties for climate change mitigation in alkaline soils, different modification methods could have been effective. In this manuscript, based on the previous work and recent advances in these modification techniques including ball milling, microwave modification, biological modification, etc. will be discussed while the focus will be on its environmental applications. The characteristics of modified biochars are mainly influenced through pyrolysis conditions, feed-stocks and modification techniques (Wang et al. 2017). A wide range of feed-stocks are used to produce modified biochars but the production conditions and applications of these biochars needs careful attention to understand their specific characteristics for long term beneficial applications. The adsorption properties of modified biochars are largely determined by their porosity, surface functional groups, and specific surface area. Therefore, according to different application requirements, the synthesis of these modified biochars can be directed since the characteristics of feed-stocks, preparation methods and conditions can change the performance of modified biochars (Tripathi et al. 2016).

The porosity of biochar can be modified to a certain extent by the selection of feed-stocks or by modifying raw material through biological, chemical and physical modification techniques or by a combination of any of these techniques. In biological modification, the biomass is pretreated with anaerobic digestion or bacterial conversion (Zhang et al. 2017). After anaerobic digestion, the digested biochar showed higher pH, surface area, cation and anion exchange capacity, hydrophobicity and more negative surface charge than pristine biochar (Inyang et al. 2010). The physical modification includes gas activation, magnetic modification, microwave modification, and ball milling. Physical modification improves pore structure, introduces oxygenic functional groups and more beneficial than chemical modification since physical modification agents are easy to control (Qian et al. 2015). The physical modification increases the adsorption capacity of modified biochar to organic pollutants by increasing the specific surface area and creating more micropores and mesopores on biochar. The advantages of physical modification include no added

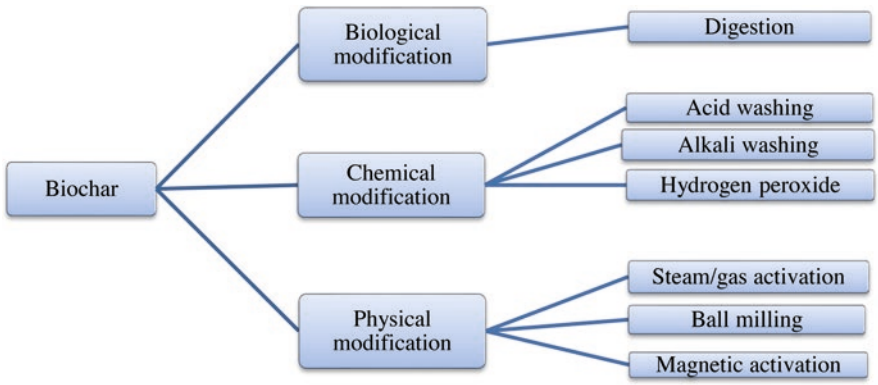

Fig. 7.2 Schematic diagram of biochar modification techniques

impurities and low cost. Chemical Oxidation means oxidation of the biochar surface to increase the oxygen-containing functional groups which increase its hydrophilicity, pore size and structure, adsorption capacity. Most commonly used oxidation chemicals are hydrochloric acid, nitric acid, hydrogen peroxide. It has been found that compared to hydrochloric acid, nitric acid provides more oxygen-containing functional groups. Chemical modification can significantly increase the acidic groups on the surface of activated carbon, improve the surface hydrophilicity of biochar and reduce the pH value which may suit alkaline soils to achieve the benefits of climate change mitigation.

An increasing interest in the beneficial application of biochar has opened up multidisciplinary areas for research. Biochar could be an efficient sorbent of various contaminants both organic and inorganic because of its huge surface area and special structure (Xie et al. 2015). The ultimate purpose is to apply differently modified biochars into environmental, agricultural, and energy sustainability. As a low-cost and efficient amendment, biochar could be used in different areas. The multiple areas where modified biochar applications could potentially be used in include carbon sequestration, soil fertility improvement, water/soil pollution remediation, and climate change mitigation (Tan et al. 2017) (Fig. 7.2).

7.4 Stability of Biochar in Alkaline Soils

The stability of biochar is fundamental to its efficiency in reducing greenhouse gas emissions. The most important feature of biochar is its very long stability in soil compared to other f organic amendments. The mineralization of other organic amendments is more rapid in alkaline soils due to temperature extremes (Nguyen et al. 2008). It has been well documented that other organic biomasses have much shorter retention in the soils compared to biochar. The average residence time of biochar in soil is about 10,000 years (Rasul et al. 2016). The stabilization of organic material in alkaline soils due to presence of calcium is better (O'Brien et al. 2015) which was also confirmed by Oades (1988) who reported better and longer soil organic carbon retention in alkaline calcareous soils which could be attributed to decreased solubility of organic carbon due to the presence of calcium. So, the addition of biochar to soil can serve as a carbon sink with greater potential. Several factors such as parent material, soil types and temperature of pyrolysis determine biochar stability (Leng et al. 2019) so studied regarding retention of biochar and its impact on combating climate change needs thorough investigations in alkaline soils since the data regarding this aspect is lacking but literature review shows that biochar with some modifications has great potential to be exploited as tool for climate change mitigation in alkaline soils.

7.5 Impact of Biochar on Soil Carbon Sequestration

The biochar sequestered carbon is highly resistant to decomposition due to its recalcitrant nature. Thus biochar application promotes carbon-negative process in the natural carbon cycle as it slows down the conversion of soil carbon to atmospheric carbon dioxide. It retains carbon to stable soil carbon pool. The advantageous effects of returning carbon dioxide from the atmosphere and addition of biochar reduce greenhouse gases emission and escalate soil functions (Lehmann et al. 2006). It has been estimated that Earth's soils are stored around four times more organic carbon than in atmospheric carbon dioxide (Lehmann 2007). While evaluating for carbon sequestration potential stability of biochar is an important parameter since only a long half-life will ensure a relevant sequestration potential by offering a wider resistance towards decomposition of biochar through soil microbial communities. Stability of biochar simply determines how long carbon held in the soil in the form of biochar will remain sequestered in soil system and at the same time how long it may influence emissions of greenhouse gas from the soil system and help in the counterbalancing the effect of climate change. It has been found that conversion of plant biomass to biochar using pyrolysis process followed by its application to the soil increases the residence time of carbon in the soil as compared to when same plant biomass applied directly to the soil. The benefits of biochar in terms of higher carbon sequestration have been found significantly greater with increase in the stability of charred product (Yadav et al. 2017). It has been widely reported that the biochar contributes to soil recalcitrant carbon pool (Marris 2006). Therefore, it is a promising strategy to sequester more carbon compared to traditional agricultural practices involving direct incorporation of plant biomass in the form of crop residues that result in rapid mineralization of carbon leading to larger carbon dioxide release in the atmosphere (Bruun et al. 2011).

7.6 Impacts of Biochar on Carbon Dioxide Emissions

Carbon dioxide is a potent greenhouse gas and is responsible for global climate change due to its increasing atmospheric level. Chemical nature of soil including alkaline soil pH and intensive agricultural practices with low potential of carbon retention in alkaline soils are responsible for the increase in atmospheric carbon dioxide since high temperature promotes rapid mineralization of organic matter in these soils. Biochar, as a key technology, has been widely added to farmland soils to moderate global climate change. Biochar is highly resistant to degradation due to its recalcitrant carbon and it has potential to improve soil quality (Zimmerman et al. 2011). The addition of biochar has been documented to alter the soil porosity, moisture content, pH, labile C and N pool sizes which would markedly impact soil carbon dioxide emissions (Stavi and Lal 2013). However, previous studies have shown that biochar addition with different raw materials and different soil types can have different effects (an increase, decrease or no effect) on the carbon dioxide flux in the laboratory or field experiments (Wang et al. 2014). The underlying mechanism of carbon dioxide emissions induced by the addition of biochar is still needed investigation, especially for alkaline soil to obtain maximum benefits. Some studies have shown that biochar addition of biochar promote mineralization of soil organic carbon and correspondingly increase emissions of carbon dioxide (Luo et al. 2011). However, some studies reported a decrease in mineralization rate thereby causing a decrease in carbon dioxide emissions (Singh and Cowie 2014). The interactions of biochar and soil properties contribute to the different processes of soil organic carbon mineralization (Cely et al. 2014). Therefore, it is important to clarify the changes in soil carbon mineralization and the variation in the behavior of biochar after its incorporation into the soils. Shen et al. (2017) found in his study that biochar amendments in agricultural soil may serve as a potential tool for climate change mitigation, with lowering carbon dioxide emissions and higher dry matter production in semi-arid farmland over a longer period.

7.7 Impact of Biochar on Nitrous Oxide Emission

In recent times, the focus of biochar conditioner research has been on soil gases flux particularly on nitrous oxide emission. Most of research findings revealed that biochar is effective in decreasing the nitrous oxide emission while few studies have shown negative or no effect. The impact of biochar on nitrous oxide emission is variable and depends on factors including soil type, soil moisture, fertilizer application, biochar feed-stock, and pyrolysis conditions (Zhang et al. 2010). Liu et al. (2014) stated that the potential mechanisms were explored by terminal restriction fragment length polymorphism and real-time polymerase chain reaction. A lower relative abundance of bacteria such as ammonia-oxidizing bacteria and nitrite-oxidizing bacteria were observed at 4% biochar application rate. Reduced copy numbers of the ammonia monooxygenase gene amoA and the nitrite reductase gene nirS coincided with decreased nitrous oxide emissions. Therefore, biochar may potentially alter nitrous oxide emission by affecting ammonia-oxidizing and denitrification bacteria which is determined by the application rate of biochar in soil. A consistent observation is that gas emissions are dependent on pyrolysis temperature and amendment rates and the ethylene generated by fresh biochars may be linked to decreased nitrous oxide production (Spokas and Reicosky 2009). One important reason to increase the atmospheric concentration of nitrous oxide ranging from 0.2 to 0.3% per year is due to human activities. Among which about 80% is derived from agriculture (Beauchamp 1997) caused by the intensive use of nitrogenous fertilizers. The reduction in soil nitrous oxide production and emissions following biochar application may be due to increased plant nitrogen use efficiency which leaves lesser nitrate in the soil for denitrification, or there may be some direct influence on the soil physical and chemical properties that are critical to soil nitrogen transformations. In alkaline soils where nitrogen losses are high could be due poor soil structure and high soil pH which favors the nitrate and ammonia losses thereby restricting plant uptake. Biochar improves soil structure and hinders nitrogen losses. This may reduce the nitrous oxide emission ultimately.

7.8 Impact of Biochar on Methane Emissions

Global warming caused by greenhouse gases emission is a serious threat to human society. Methane is an important greenhouse gas with 28 times global warming potential than carbon dioxide with a unit mass at 100-year scale (IPCC 2013). The pre-industrial atmospheric concentrations of methane were 0.715 ppmv which currently measures 1.774 ppm and maintain a 0.6% increase in speed annually (Zhu et al. 2011). Studies have shown that methane emitted from soil accounts for 15–30% of the total emissions every year (Qu et al. 2016). Pratiwi and Shinogi (2016) revealed that soil properties such as increased saturated hydraulic conductivity and macro-porosity which cause methane emission could be improved with biochar application. In addition, decreased methane emission may be related to N speciation. The results showed that biochar amendment significantly reduced methane emissions by 45.8 and 24.1 kg per hectare and suppression was weaker along with increasing biochar addition level. Reduced methane emissions might be associated with decreased ratios of methanogenic archaea to methanotrophic proteobacteria and the increase in oxygen supply due to biochar application supports a group of aerobic methanotrophs (Feng et al. 2012). Soil texture and biochar pH are two critical properties affecting the response of soil methane flux to biochar addition.

7.9 Impact of Ammonia Emissions and Nitrate Leaching

The global ammonia production by human activities such as combustion of nitrogen-containing biomass, fossil fuels and use of ammonia-based fertilizers is estimated 45.0 million tons per year. It is very necessary to investigate some suitable techniques for controlling ammonia emission. The absorption and incineration have been used to eliminate ammonia emissions before releasing it to atmosphere (Guo et al. 2005) but using dry adsorbents for controlling emission of is very efficient approach which has attracted much attention due to its simplicity and economic feasibility in configuration and operation (Rodrigues et al. 2007) and also reported that ammonia adsorption by activated carbon it was found that more amounts of adsorbent had to be used for higher efficiency. Biochar can be used for various purposes can also be promising for ammonia adsorption onto its surface. Since capturing ammonia from soil is practicable using biochar, removal of ammonia from foul air using biochar might also be possible in alkaline soils since it is a big issue due to temperature extremes.

Studies conducted in different parts of the world have shown that farmers often use the variety of nitrogen fertilizers that exceed the nitrogen requirement of crops. Most of the studies conducted on nitrate leaching are from the regions where rainfall is abundant and well distributed but studies under semiarid condition are scares (Uusitalo et al. 2001). The consumption of high level of nitrate may cause health problems such as cancer and teratogenicity effect. Sandy soils consist of coarse soil particles and have a loose texture, making these soils particularly vulnerable to water and fertilizer loss, as well as relatively nutrient-poor (Zhang et al. 2015). Alkaline soils are generally impermeable and have little organic matter, with pH levels typically exceeding 7.5 are prone nitrate leaching (Huo et al. 2017).

7.10 Conclusions and Future Research Directions

Climate change mitigation by using biochar reduces the emissions of greenhouse gases from the soil. At present it is impossible to predict the emission reductions with biochar but it is possible to probe the potential of biochar to mitigate the climate change. Available research data and results under various conditions strongly justify continued research and development efforts in understanding more about the benefits and potentials as well as limitations of biochar and expanding its use in land management. The beneficial role of biochar application on the broader issues of climate change mitigation and sustainable agriculture invites further research to explore its true potential. Various technologies evolved and finished overtime except the ones which really benefitted humanity. The adoption of biochar in alkaline soils is under research process and solid outcomes of the application of biochar are not yet evident but in long term studies involving all proposed modification will surely yield better outcomes since all the indicators are in favor to achieve desirable results including climate change.

Alkaline soils constitute the one-fourth of world's farmlands which require organic amendments for carbon retention and to reduce soil pH. Recent research has proved that biochar is the most stable carbon source to mitigate climate change. Additionally, oxidation of biochar over time and some modification strategies may result low pH biochar which can potentially be exploited to combat climate change and other benefits in alkaline soils.

Further research-based studies on application, quantification of impact, feasibility of production and economics of using the biochar from environmental perspective may help in developing biochar science and technology in agricultural and environmental sciences. Pilot-scale studies to long term large scale studies at the various research stations. These directions may provide some insights into how the biochar affects net climate forcing from soil greenhouse gases flux and offers recommendations for the development and improvement of efforts against climate change in alkaline soils.

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Chapter 8
Biochar; a Remedy for Climate Change

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Abstract Researchers and scientists have agreed upon a commitment to lower greenhouse gases (GHG) emission values by 40–70% compared to 2010 values and to keep the temperature rise at 1.5 °C by mid-century. Several proposed solutions have been put forward by scientific community to fulfill this commitment. Biochar is an emerging solution to problems relating soil and environmental degradation due post green revolution measures taken by humanity to boost agricultural production. Being rich in carbon and having greater stability, biochar has several benefiting properties such as surface area, porosity, water holding capacity, adsorption capacity, and cation exchange capacity that may persist for decades or even centuries. These properties greatly help in sustainably maintaining soil and environmental health and increasing crop production. Besides, biochar has been proven to have great carbon sequestration capacity. Biochar in its original form and after physical

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_8

or chemical activation has been found to be an excellent CO_2 adsorbent with stable recyclability and regeneration. It also increases soil aeration, hence decreasing the activities of methanogens and consequently reducing methane emissions. Biochar increases the C:N ratio of the soil which according to several researchers may help reduce nitrous oxide emissions from the soil. Biochar has also been proven an effective sorbent for organic and inorganic wastes including heavy metals and pesticides. This sorbent capacity of biochar comes from its greater surface area and microporosity which can be further increased by techniques employed during pyrolysis. In its climate change mitigation efforts, biochar is a suitable alternative to fossil fuel driven energy production. Biochar has been used in the production of clean energy sources such as for sorption of hydrogen, development of super capacitors, as solid acid catalyst for biodiesel production and as cathodes in fuel cell systems such as Direct Carbon Fuel Cell (DCFC) and Microbial Fuel Cell (MFC). This chapter provides with ample examples from previous and ongoing studies that makes biochar a potential candidate among solutions being put forward by scientific community to mitigate the adverse effects of climate change.

Keywords Climate change · Biochar · Greenhouse gases · CO_2

8.1 Introduction

Biochar is a carbon rich material produced from plants and other waste feedstock by thermochemical decomposition or pyrolysis at temperature ranges of 350 and 700 °C under oxygen-limited conditions and is specifically used for maintaining soil and environmental health (Lehmann 2009). Major benefiting properties of biochar that help in promoting soil health and environmental conservation include its surface area, porosity, adsorption capacity, water holding capacity and cation exchange capacity. It has great stability and is very resistant to any kind of physical, chemical or biological degradation.

Intergovernmental Panel on Climate Change in its 2014 report has expressed concern over the rising levels of greenhouse gasses (GHGs) in earth's atmosphere and called for action. By mid-century the GHG levels must be lowered by 40–70% compared to 2010 values. Various mitigation strategies and a growing number of policies have been employed to combat climate change (Fahad and Bano 2012; Fahad et al. 2017; Fahad et al. 2013; Fahad et al. 2014a, b, 2016a, b, c, d, 2015a, b, 2018, 2019a, b; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib ur et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar-uz et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017). Given the tremendous properties of biochar, scientists are gathering interest in its possible use as a climate change mitigation strategy. The term "biochar" has never been used in association with climate change before 2005 (Verma et al. 2014). The degree of stability that biochar exhibits has gathered attention of researchers. By converting biomass into biochar a tremendous amount of Carbon can be sequestered and stored in the soil for a long period of time. Besides stability, other properties of biochar such as its excellent adsorption capacity can be of a better use in an ever polluting environment.

However, a few comprehensions regarding the production and use of biochar must be considered. Firstly, as a product of combustion, it is a matter of concern that biochar be produced with least GHG emissions. The reactors and plants designed for biochar production must be efficient enough to convert maximum amount of biomass to biochar with few or no GHG emissions (Sayigh 2012). Secondly, it must not compete with food production and should be produced from waste feedstock. The agricultural land that is dedicated to the production of energy crops must not be specifically used for feedstock production. Thirdly, and most importantly, it must not pose any danger to the environment or fertile soil. The International Biochar Initiative (IBI) launched in 2013 is major step taken by policy makers round the world that helps in this regard. Biochar manufacturers are now able to certify that the biochar they produce is safe for soil and environment.

8.2 Biochar and Soil Health

Before initiating any climate change mitigation program, it is necessary to assess the suitability of the material aimed for mitigation purposes. Biochar, an organic source, was originally used to improve soil fertility and productivity. The idea stemmed from "tera peta" soil that contained high amount of biochar since thousands of years ago and maintained unusual productivity for a longer period of time. Besides the presence of labile carbon for soil improvement, other reasons may include water retention (Ayodele et al. 2009), increased nutrient availability, adjustment of soil pH and enhanced microbial activity (Theis and Rillig 2009). One may wonder whether biochar may add any pollutants to the soil. It has been established that organic residues may contain heavy metals and upon decomposition these heavy metals may retain in the soil, posing a soil health hazard if applied in uncharred form. Making biochar from the feedstock may lock these metals in charred material for a long time but eventually they will release. So addition of heavy metals through addition of biochar is a least concern. Biochar has been rather proved to be a remedy for soils containing heavy metals. This can be attributed to the excellent cation exchange capacity which cause adhesion of heavy metals ions with biochar particles and prevent active uptake through plants (Shinogi 2004).

Regarding addition of pollutants to the soil, a matter of concern about biochar is the production of hazardous compounds such as PAHs and dioxins during pyrolysis. This generally happens when feedstock having concentrations of heavy metals is pyrolysed. But reports has it that organic pollutants such as chlorinated benzenes and phenols are formed at 750 °C. This temperature is way above the common pyrolysis temperature. Dioxins production is also prevented due to the absence of oxygen in pyrolysis process and absence of chlorine in biomass. However, the formation of PAH is most likely to happen at temperatures above 400 °C, though, formation of more hazardous tertiary PAHs occurs only above 700 °C (Hajaligol et al. 2001). The scientific community must share the burden of providing knowledge for the identification of suitable biochar properties and production conditions.

8.3 Biochar's Stability

The key difference between biochar and other organic carbon forms is biochar's stability. Like other forms of organic matter and plant residues, biochar's decay depends upon a variety of factors. These include type of substrate, pyrolysis temperature, soil type and mineralogy, soil microbiology and moisture. As a form of organic source, biochar will eventually decay but much more slowly than any other form of organic matter (Baldock and Smernik 2002). The reason behind great stability of biochar is its chemical recalcitrance which is due to the presence of aromatic structures. Although biochar also contains a fraction of labile carbon which readily decomposes, however, a great portion of biochar is composed of recalcitrant carbon which takes 100 s to thousands of years to decompose in soil and even more under oceanic conditions (Pessenda et al. 2001). The ability of biochar to mitigate the adverse effects of climate change depends upon the production efficiency, the amount of energy it needs for production and the amount of emissions it is expected to reduce. Traditional biochar production efficiency will have a low impact on climate change as compared to a highly efficient biochar production system which converts maximum biomass to carbon. Energy capture during pyrolysis is yet another factor in this regard. Bio-oil and syngas is a product produced during pyrolysis which could be used as a fuel if captured, otherwise it is lost to atmosphere as emissions.

This fact has great impact on assuming biochar as a mitigation strategy. This can be exemplified by a highly efficient modern biochar production system which converts 50% of biomass carbon to biochar that we can expect of having a mean residence time of 100 years. However this residence time cannot be termed as effective for long term sequestration and the mean residence time must exceed a few hundred years. Most of the observations about mean residence time are mere assumptions and in fact a mean residence time could not be agreed upon. The reason behind this are the uncertainties in quantifying the portions of recalcitrant and labile carbon in biochar (Lehmann et al. 2009). Biochar production system needs to produce biochar with maximum recalcitrant portion with mean residence time of several thousand years.

8.4 Biochar for Climate Change Mitigation

Biochar can be used as a mitigation strategy in several areas of varying interests. Major environmental benefits of biochar include carbon sequestration, carbon dioxide adsorption, GHG emissions reduction, pollutants adsorption and use of biochar in production of renewable energy.

8.4.1 Carbon sequestration

Carbon sequestration is a process by which carbon is prevented from being emitted to the atmosphere and instead captured as well as stored as a stable and inert material in a sink. Scientists have agreed upon that biochar's stability gives it the ability to sequester carbon for a longer period of time. Biochar offers an easy choice to store carbon as a passive pool. It has been estimated that the annual uptake of carbon by plants is eight times greater than that of which is produced by anthropogenic GHGs emissions. Therefor storing a small amount of carbon in the soil will greatly reduce GHG emissions (Shafie et al. 2012). Biochar has the ability to capture 20% of the total carbon biomass as a stable carbon matter which means that approximately 20% of the total carbon biomass can be captured by conversion into biochar (Lehmann 2009).

8.4.2 Biochar's and GHG Emissions Reduction

It has been recognized that the decrease in GHG emissions for mitigating climate changes is globally necessary. The Kyoto protocol and Paris Agreement listed carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF_6) as GHGs that need to be mitigated. The contribution of these gases in global warming is influenced by their potency, abundance and properties. CO_2 is taken as a standard and other GHGs are compared with it in their magnitude in capturing the sun's heat. Among these GHGs, PFCs, HFCs, and SF_6 are GHGs have the highest global warming potential of several thousand times greater than CO_2, while N_2O and CH_4 have global warming potential 298 and 25 times greater than CO_2. However, the large amount of CO_2 being emitted into the atmosphere makes it to contribute 55% alone to global warming.

It is a subject of current investigation whether biochar, upon addition to soil, increases or decreases GHG emissions from the soil. It is not perfectly clear whether the decomposition of organic matter slows down or speeds up with the addition of biochar. Proponents of both sides have their things to say. Research on biochar systems lasts for short durations and upon these studies it has been established that biochar actually increases the decomposition of organic matter (Hamer et al. 2004; Spokas et al. 2009). This has been majorly attributed to the enhancement of microbial activity partly due to the presence of labile fraction in biochar, its high cation exchange capacity and pH adjustment of acidic soils. On the other hand, many researchers upon the measurements of CO_2 in the vicinity, could not detect any increase in the decomposition of soil organic carbon in biochar amended soils (Li et al. 2014b).

8.4.2.1 CO_2

CO_2 emissions have been greatly increased due to industrialization and currently the emissions made in the past two centuries account for almost 40% of the totals emissions made ever in history (Spigarelli and Kawatra 2013). The concentration of CO_2 has risen to 410 ppm in February 2019 from 280 ppm in the 1760s (Rashidi and Yusup 2016). It has been forecasted by the Intergovernmental Panel on Climate Change (IPCC) to reach 590 ppm by the end of twenty-first century causing an average rise in global temperature by 1.9 °C (Li et al. 2014a).

Woolf et al. (2010) analyzed that sustainable global implementation of biochar proposal has the potential to decrease current anthropogenic CO_2-C equivalent emissions by 12%, which translates to 1.8 Pg CO_2-Ce per year of the annual emissions which stands at 15.4 Pg CO_2-Ce. In this way the net offset of biochar solution could be 130 Pg CO_2-Ce over the course of one century (Woolf et al. 2010). Biochar in its original form and after physical or chemical activation has been found to be an excellent CO_2 adsorbent with stable recyclability and regeneration.

8.4.2.1.1 Activated Biochar and CO_2 Adsorption

Activation results in tremendous increase in surface area and micropores in biochar. Biochar activation for CO_2 adsorption can be generally done via four methods. i.e. (1) physical activation, (2) chemical activation, (3) surface functionalization, (4) heteroatom doping and metal/metal oxide impregnation (D'Alessandro et al. 2010; Qian et al. 2015; Tan et al. 2017). These methods could be used alone or in combination. Physical and chemical activations have two steps, pyrolysis of biomass at high temperatures (300–900 °C), followed by the activation of biochar with oxidants such as O_2, CO_2 or steam at high temperature (500–900 °C). Chemically activated biochar has been found to have more CO_2 adsorption capacity as compared to physically activated biochar, however, additional inputs such as KOH are needed for chemical activation. Chemically activated biochar also needs to wash intensively after activation process in order to remove residual chemicals. Other methods for activation of biochar are surface functionalization, heteroatom doping and metal/metal oxide impregnation. These two methods could be used even after physical or chemical activation of biochar. Surface functionalization could be achieved by doping the activated biochar with N and amine functional groups. Most of other functional groups on the activated biochars such as amines, amides, hydroxyl and azo compounds have been found effective to adsorb CO_2 gas at mild temperatures (30–60 °C). After adsorption of CO_2 on the functional groups, the functional groups are converted to carbamic acid, carbamate, nitrate aldehyde, and N containing heterocyclic groups. After CO_2 desorption from the functional groups at high temperatures, most of the functional groups are regenerated (Zhang et al. 2017). Impregnation of alkaline metal/metal oxides (i.e. Al, Mg, Fe, Na Ni, and other oxides) into biochar is yet another method for improving CO_2 adsorption.

Ello et al. (2013) pyrolysed Africa palm shells at 600 °C for 1 hour, then activated the produced biochar with KOH at 860 °C for 1 hour, followed by neutralization, water washing, and drying. They noticed significant increase in surface area, pore volume and micropores formation in the chemically activated biochar compared to biochar without activation. Surface area increased from 365 to 1250 m2 g^{-1}. CO_2 adsorption increased from 1.9 to 4.4 mmol g^{-1} at 25 °C and 1 bar after activation. Zhang et al. (2016) produced biochar from black locust through pyrolysis, chemically activated a part of it with KOH and then applied thermal treatment of the biochar under NH_3 and N_2, which led to amine functionalization and nitrogen doping (Zhang et al. 2016). They obtained a CO_2 adsorption value of 5.05 mmol g^{-1} at 25 °C and 1 bar on the N and NH_3 treated biochar, which was 35% higher than chemically activated biochar and 2.7 times higher than non-activated biochar.

Nowrouzi et al. (2018) compared CO_2 adsorption of simply activated Persian wood biochar with impregnated binary metal oxide biochar and monometallic oxide impregnated biochar. CO_2 adsorption capacity increased from 3.02 mmol g^{-1}at 30 °C and 1 bar of activated biochar to 6.78 mmol $g^{-1}$of biochar impregnated with copper oxide. Other metal oxides also showed high CO_2 adsorption capacity at the same condition and are given as: 6.27 (Cu/Ni oxides), 6.48 (Ni oxide), 6.18 (Mg/Al/oxides), 5.98 (Mg oxide), and 5.82 (Al oxide).

It is upon scientific community to develop ways of biochar activation that use less energy, chemical inputs and take less time to activate.

8.4.2.1.2 Biochar Contribution to CO_2 Emissions

It is a subject of debate whether biochar production contributes to global warming by emitting GHGs such as CO_2. A life cycle assessment carried out by Yang et al. (2016) at a pyrolysis plant in China showed that the pyrolysis process itself contributed to 89% of its GHG emissions. The rest of operations in biochar production and delivery such as building, equipment and transportation contributed to the remaining 11% of GHG emissions (Yang et al. 2016). However, many researchers have calculated the net GHG emissions from biochar systems to be negative. For instance, Alhashimi and Aktas (2017) compared the GHG emitting potential of several biochars such as sewage sludge, poultry litter, food waste and cattle manure. They found net negative emissions for almost all biochar cycles averaging −0.9 kg CO_2eq kg^{-1}. This indicates that more GHG is consumed than emitted (Alhashimi and Aktas 2017). Yang et al. (2016) suggested that if best pyrolysis techniques are employed and only 41.02% of all biochar produced at Hubei Pyrolysis plant at China is returned to soil, the net GHG emissions would be zero, assuming that rest of biochar was produced at the expense of GHG emissions but not applied to the soil for carbon sequestration and used elsewhere causing GHG emissions directly to the atmosphere. So it can be concluded that biochar reduces the net GHG emissions released at its production expenses.

Reports of biochar application increasing CO_2 emissions from the application site have also been received (Polifka et al. 2018). Sagrilo et al. (2015) compiled the results of 46 studies about CO_2 emissions in biochar amended soils in a meta-analysis. A statistically significant increase of 28% in CO_2 emissions was found from biochar amended soils, indicating an acceleration in the loss of soil organic carbon and hence questioning the ability of biochar to sequester carbon. However, this increase in CO_2 emissions have been only attributed to the ratio of biochar C to soil organic carbon (SOC) and the albedo impact caused by biochar. They assessed that when the ratio of biochar C to SOC was greater than 2, a significant increase in CO_2 emissions was observed. However, no significant increase in CO_2 emissions were observed when the ratio was less than 2. Meyer et al. (2012) studied biochar amendment as potential GHG emissions mitigator taking into account the impact of albedo. A modeled biochar system and its albedo impact for the overall GHG mitigation benefits and found that it benefited the overall emissions by 13–22% for the changing albedo. Gupta et al. (2018) used biochar as carbon sequestering additive in cement mortar and found positive results in terms of global warming reduction.

8.4.3 Other GHGs

Besides CO_2, biochar also has the potential to reduce other GHG emissions to the atmosphere such as methane and nitrous oxide (Bruun et al. 2011; Laird 2008).

8.4.3.1 CH_4

CH_4 is 20 times more potent in trapping heat as compared to CO_2. The earth's atmospheric CH_4 concentration has increased by ca. 150% since 1750, and it accounts for 20% of the anthropogenic warming effect. CH_4 is emitted via natural sources such as wetlands and human activities. Naturally it is produced by many processes including that produced by anaerobic methanogenic bacteria in the soil by a process called methanogenesis (Noble et al. 2000).

Results regarding methane emissions from biochar amended soils are mixed too. To evaluate the actual benefits of biochar for mitigating CH_4 emissions, it is necessary to quantify the effect of biochar on CH_4 production from amended soils, especially in wetland, where soils are routinely drained and flooded, thus accelerating the CH_4 and N_2O emissions.

Biochar increases soil aeration thereby reducing anaerobic conditions in the soil and hence decreasing the activities of anaerobic bacteria. Rondon et al. (2005) found methane emissions to be close to zero in a soil applied with 2% w/w biochar. Liu et al. (2011) showed a net decrease in CH_4 emissions from rice fields with biochar application. Rondon et al. (2005) reported a decrease in methane emissions from maize field amended with biochar in a tropical climate. Liang et al. (2016) reported a significant reduction in CH_4 emissions from paddy fields with the application of cornstalk biochar. This decrease has been attributed to an increase in methanotropic bacterial abundance as well as decrease in the ratio of methanogenic to methanotropic abundance.

Knoblauch et al. (2008) reported no impact on methane emissions from rice paddy while Spokas et al. (2009) reported increase in methane emissions on temperate soils with biochar additions. Zhang et al. (2010) reported increase in CH_4 emissions from paddy soil augmented with biochar. The possible reason for this contradiction has been attributed to the variation in physico-chemical properties of the biochar, soil type, soil fauna and soil/nutrient management practices (Xiong et al. 2007).

8.4.3.1.1 Composting with Biochar and CH_4 Emissions

Composting with biochar has been found helpful in reducing GHG emissions from compost. Sonoki et al. (2013) applied poultry litter with 10% biochar and observed a decrease in CH_4 emissions during the thermophilic phase due to an increase in methanotrophs and decrease in the number of methanogens. Vandecasteele et al. (2013) also added 10% biochar to composting municipal solid waste and green-waste and observed a decrease in CH_4 emissions. The exact mechanism of biochar reducing GHG emissions from compost has not been fully explored but it is widely believed that same mechanism is employed in compost as in the soil. It has been hypothesized that biochar alters the physical and chemical properties of compost such as pH, moisture and temperature of compost and hence make it to reduce CH_4 emissions.

8.4.3.2 N_2O

N_2O is one of the most important greenhouse gases having great global warming and ozone depleting potential (Ravishankara et al. 2009). The atmospheric concentration of N_2O currently stands at ~324 parts per billion by volume, way up above the pre industrialization value of 270 parts per billion by volume. The main source of global anthropogenic N_2O emissions owes to the access use of nitrogenous fertilizers and the N transformation that occurs due to microbial activities in the soil. Nitrous oxide (N_2O) is more potent in heat capture than CH_4 and is mostly produced by soil microorganisms through nitrification and denitrification processes (Noble et al. 2000).

Studies on nitrous oxide emissions reduction with biochar emissions are also scarce. Contrasting perception exists in this regard but in most studies it has been observed that nitrous oxide emissions were reduced from fields amended with biochar (Spokas et al. 2009). A small number of studies have noted increase in nitrous oxide emissions at higher moisture content and higher nitrogen addition at the start of the experiment (Singh et al. 2010). Possible reasons for this are the changes in microbial populations, changes in CO_2 by them or changes in water filled pore spaces. The reason for this is that biochar's ability to decrease N_2O emissions is greatly affected by its application rate. N_2O emissions reductions of upto 74% have been observed with higher biochar application rates (20–60%) while no reduction was observed at lower application rates (2–10%) (Spokas et al. 2009).

Emissions of N_2O are greatly affected by the moisture content in soil. More the moisture content of the soil, more will be nitrous oxide emissions (Yanai et al. 2007). Biochar is usually correlated with field moisture content as it has been reported to increase soil water holding capacity. However, surprisingly, researchers have observed reductions in N_2O emissions with biochar application. Renner reported an 80% reduction in N_2O emissions in field and greenhouse experiments in Columbia (Renner 2007). In another study, Jia et al. reported 77–82% decrease in N_2O emissions even at high moisture content and N fertilizer rates (Jia et al. 2012). Other researchers have found no reduction or mixed results. The reason behind biochar's ability to reduce N_2O emissions is it great sorption capacity (Singh et al. 2010). Biochar disturbs N cycle by sorbing access nitrate to its surface and hence reduce nitrification and denitrification process (Lehmann 2009). Biochar has a high CN ratio which causes the immobilization of inorganic N. Biochar also efficiently adsorbs NH_3 from soil and acts as a buffer and hence decrease ammonia volatilization (Van Zwieten et al. 2010).

Cayuela et al. (2014) compiled the results of 261 experiments on biochar's ability to mitigate N_2O emissions in a meta-analysis. On average, 54% reductions in N_2O emissions were found due to biochar application subject to enhanced biochar production technology. Borchard et al. (2018) also carried out a meta-analysis comprising 88 publications obtained from 608 observations up to May 2016. They found the overall reduction in N_2O emissions to be 38%. Most reductions were found in sandy soils and paddy soils. However the reductions were found to be negligible after one year (Borchard et al. 2018).

Some authors have reported reductions in N_2O emissions when mineral fertilizer was applied to the soil along with biochar. N_2O emissions were reduced upto 84% and those of NO by 67% when nitrogen fertilizer was applied in combination with biochar (Yanai et al. 2007).

8.4.4 Biochar and Useful Chemical Sorption

8.4.4.1 Biochar for Pollutants Sorption

Biochar has been proven to be an effective sorbent for organic and inorganic wastes (Ahmad et al. 2014). The excellent sorbing capacity of biochar originates from its high surface area and microporosity as well as the presence of a number of oxygenated functional groups, such as hydroxyl, carboxyl and phenolic surface functional groups on its surface. These functional groups act as binding sites for organic and inorganic contaminants (Uchimiya et al. 2011). Higher the surface area and microporosity of biochar, higher will be the organic contaminants sorption capacity. Surface area and microporosity of biochar can be increased by techniques employed during pyrolysis. It has been reported that biochar produced at higher pyrolysis temperatures (above 400 °C) have greater surface area and microporosity compared to those produced at lower temperature. Activated biochars also have greater surface area and hence more sorbing capacity.

Sorption of organic contaminants occurs in two major domains i.e. rubbery and glassy. Sorption mechanism in rubbery domain is linear and non-competitive partitioning. While the sorption mechanism in the glassy domain occurs as a nonlinear and solute–solute competitive pore-filling mechanism (Li et al. 2014b). Generally, most of biochars are not completely carbonized and have both carbonized and non-carbonized fractions. Pyrolysis temperature greatly affects the proportion of carbonized and non-carbonized fractions in biochar. It has been reported that the carbonized fraction increases when biochar is produced at higher temperature (Chen et al. 2008). Glassy domain employs the carbonized fraction of biochar (produced at higher temperature) as an adsorption phase whereas the non-carbonized fraction behaves as partition phase in the rubbery domain (Chen et al. 2008).

8.4.4.2 Biochar for Heavy Metals Sorption

Biochar has been proven to be an excellent sorbent for heavy metals in the soil (Houben et al. 2013). Biochar makes use of its high surface area and microporosity in sequestering heavy metals. The bioavailability and eco-toxicological impacts is altered when they come in contact with biochar and hence are carried out of the active uptake cycle. The presence of oxygenated functional groups on biochar surface also helps biochar in adsorbing heavy metals (Uchimiya et al. 2011).

8.4.4.3 Biochar for Physical Pesticide Removal

Biochar exhibits great potential towards pesticides removal from the soil because of the following mechanisms:

(1) Increased pesticides adsorption capacity (2) Decreased pesticides desorption capacity (3) decreased bioavailable fraction of residual pesticides in soil pore water (4) improved physico-chemical properties of soil such as water holding capacity, EC and pH.

8.4.4.4 Effects of Biochar on Biological Pesticide Degradation in the Soil

Pesticides degradation in soil comprises of several processes including biodegradation, photolysis, hydrolysis and oxidation. Like other potential pollutants such as heavy metals in soils and water contaminants, biochar helps in pesticides degradation through its excellent sorption capacity (Jones et al. 2011; Khorram et al. 2016; Tatarková et al. 2013). Although, biodegradation of pesticides is specifically carried out by soil microbes and the fact that biochar stimulates microbial community and specific microbes population has been widely established (Qiu et al. 2009). Contrasting reports of biochar increasing and decreasing the magnitude of microbial degradation of pesticides exists in literature. The physical nature of biochar due to its increased pesticides sorption and decreased desorption capacity may affect the amount of pesticide available for microbial degradation (Nag et al. 2011).

A wide range of studies reported an increase in pesticide degradation with biochar amendment which they largely attributed to enhanced microbial population in biochar-amended soil, partly due to enhanced availability of nutrients for microbial consumption (Zhang et al. 2005). Qiu et al. (2009) reported an increase in atrazine degradation due to biochar amendment. This may have resulted from an increase in nutrients by the biochar, which could have stimulated the activity of microorganisms and consequently enhanced biodegradation. Jablonowski et al. (2013) found an equally high and even significantly higher atrazine degradation in soils applied with 0.1–5% hardwood biochar compared to soils without biochar. This was attributed to high atrazine mineralization by an atrazine-adapted soil microflora which was positively affected by biochar amendment. Another aspect of increased pesticide degradation could be attributed to increased root growth which could enhance pesticide uptake by plant resulting in its removal from soil.

Some researchers have found decreased biodegradation of pesticides with biochar amendments. Jones et al. (2011) found simazine degradation in biochar amended soils after 21 days of incubation to be only 10% of soil not receiving any biochar amendments. Sopeña et al. (2012) applied red gum wood biochar to fields receiving isopteran application and reported increased sorption, decreased desorption, and hence reduced biodegradation of isoproturon. Tatarková et al. (2013) found similar results with MCPA and noted that the half-life of pesticide was increased to 21 days in biochar amended soils from 5 days in the nonamended soils. This reduction in pesticides biodegradation was attributed to the increased sorption of simazine by biochar which leaves soil with little pesticide to be degraded biologically.

8.4.4.5 Biochar Use in Clean Energy Sources

Global demand for energy is ever increasing with increasing population and urbanization (Tripathi et al. 2016). Since the advent of industrialization, fossil fuel have been the main source of energy with great environmental consequences. Recently, biochar has gathered attraction for it waste possible use in clean and renewable energy sources (Gollakota et al. 2018). Though biochar production itself yields useful energy sources such as bio-oil and syngas (Persson et al. 2018), other uses of biochar relating to energy production have been welcomed by scientists. The potential of biochar to be used for various applications depends upon its properties. For example, biochars with high structural bound oxygen groups could be used in direct carbon fuel cells (DCFC) (Kacprzak et al. 2014), while those with high structural bound nitrogen groups can be used to develop supercapacitors (Titirici et al. 2012).

Biochars with electrical conductivity, stability and porosity can be used as cathodes in microbial fuel cells (Huggins et al. 2014).

8.4.4.6 Sorption of Hydrogen

In a world of changing climate, hydrogen is considered a clean energy source. However the main obstacle faced during deploying hydrogen-based technologies is difficulty in its storing. This problem can be overcome by the use of sorbents that have high sorption rate, storage capacity and reversibility; for the physisorption of hydrogen (Lee et al. 2000). Biochar can act as an ideal sorbent due to its high physisorption capacity originating from its high surface area. Activated biochars have even more surface area so they can prove best in this regard. Zhang et al. (2010) developed corncob biochar under optimized preparation conditions which was chemically activated using KOH chemical activation with resulting large pore volume (1.94 $cm^3\ g^{-1}$) and high surface area (3500 $m^2\ g^{-1}$) and). At 1.0 bar and 196 °C temperature, activated biochar with small pore size and resulting large pore volume showed the highest hydrogen storage capacities of over 2.85 wt.%.

Loading biochar with nickel is yet another and even more promising technique for increasing biochar's ability to store hydrogen if or not activation pretreatments are applied. Figueroa-Torres et al. (2012) developed a biochar from *Quercus agrifolia* feedstock and activated it through a hydrazine based bath at 50 °C. Then they dispersed an even layer of Ni nanoparticles on it. They obtained a hydrogen storage capacity of 1.6 wt. % from the nickel loaded activated carbon which was twofold as compared to the hydrogen storage capacity of activated carbon without the nickel layer.

8.4.4.7 Use in Super Capacitors

Supercapacitor is a latest energy storage device which has recently gathered attention for its ability to efficiently harvest electrical energy and later on its use in digital communication systems and electric vehicles. It has high-power density, long life cycle and quick charge/discharge capability (Xiao et al. 2012). High quality and low cost carbon material with large micropores density and high surface area are primarily used for the development of supercapacitors due to its wide availability and low environmental impacts (Liu et al. 2012). Several researchers have tried to develop supercapacitors from wood-derived biochars and obtained satisfactory results in terms of improved capacitance, low cost and environment friendliness (Goodman et al. 2013). It has been estimated that supercapacitor biochar electrodes have a potential window of about 1.3 V and fast charging–discharging behavior with a gravimetric capacitance of about 14 F g^{-1} (Jiang et al. 2013). Further, biochar can be activated with chemicals such as nitric acid and even improved capacitance of upto 115 F g^{-1} (Jiang et al. 2013) and 234 F g^{-1} (Liu et al. 2012) can be obtained. This increase in capacitance is attributed to the development of surface oxygen groups such as carboxyl groups and hydroxyl groups after activation of biochar with nitric acid.

8.4.4.8 Solid Acid Catalyst for Biodiesel Production

Biodiesel is a clean and environment friendly source of fuel and is gaining momentum in its use in a world of changing climate. Esterification and transesterification of animal fat and vegetable oil is achieved for the efficient production of biodiesel. For this purpose, acid catalysts of both homogenous and heterogeneous nature are commonly used. Biochar has been recently proven to be a good precursor for producing heterogeneous acid catalysts (also called solid acid catalyst). For this purpose, biochar is usually activated and then treated with sulfuric acid (Dehkhoda and Ellis 2013). Dehkhoda and Ellis (2013) successfully developed a biochar-based solid acid catalyst by chemically treating biochar with KOH and then sulfonating the biochar with concentrated sulfuric acid. The catalyst was successfully used for the transesterification of canola oil with alcohol and oleic acid. The catalyst yielded upto 48.1% with a high reusability of about 8% which means that the yield was only decreased by 8% when reused.

8.4.4.9 Biochar in Fuel Cell Systems

Fuel cells are efficient and low GHG emitting energy generating units which convert chemical energy into electrical energy. They typically have an anode, a cathode and an electrolyte fuel in the form of many kinds of fluid including aqueous alkaline solution, polymer membrane (ionomer), molten alkaline carbonate and liquid hydrogen. They were first developed in 1938 but their practical use came a century later by NASA in their space missions. Recently, the possibility of using carbon as a fuel in fuel cell is gaining popularity. Biochar use in two of the most widely used fuel cell system is given below.

8.4.4.10 Direct Carbon Fuel Cell (DCFC)

Ahn et al. (2013) developed a direct carbon fuel cell (DCFC) to convert molten carbonaceous solid fuel directly into electricity. They compared the performances of biochar and coal in DCFC systems and found the fuel cell power density of biochar as fuel to be 60–70% of the coal-based fuel. This comparably low power density of biochar originates from its low carbon and higher ash contents but this indeed shows the possibility of using biochar as a low cost renewable fuel for DCFC. Other researchers e.g. Kacprzak et al. (2014) also found biochar to be a promising DCFC fuel alternative to coal.

8.4.4.11 Microbial Fuel Cell (MFC)

MFC is yet another electricity generating technology with an additional benefit of removing organic and inorganic contaminants from soil or wastewater (Raveendran et al. 1995). MFC makes use of exoelectrogenic bacteria which oxidise the fuel on MFC anode and hence electrons are generated from the bacteria in the cell which flows through an external circuit to reach cathode, completing the circuit and thus generating a current. However, the commercialization of MFC is limited by the non-renewable nature and high cost of electrode materials used in MFC. Mostly the electrode material comes in the form of graphite granules or granular activated carbon which are cost prohibitive (\$500 to \$2500 ton^{-1}) (Huggins et al. 2014). Biochar can also be used as a low-cost anode material on MFC (Chen et al. 2008). Huggins et al. (2014) compared the cost and power output of graphite and activated carbon electrodes with a wood-based biochar electrodes and found that power output cost of biochar (\$35 W^{-1}) was 90% lower than that of graphite (\$392 W^{-1}) and activated carbon (\$402 W^{-1}). Biochar has also been used as an efficient catalyst in MFC (Yuan et al. 2013).

8.5 Conclusion

Climate change and resulting global warming are of particular concern for today's scientists. Agriculture sector is a major contributor to this change due to extensive cultivation practices and land clearance. However, the remedy for climate change also lies in this sector. A major part of CO_2 released due to any kind of anthropogenic activities is absorbed by agricultural and non-agricultural plants. This absorbed CO_2 is converted into biomass thanks to the reaction of life i.e. photosynthesis. But in the universe, everything goes in a cycle and that assimilated biomass upon decomposition once again is released into the atmosphere as greenhouse gases. The remedy lies here; to store that assimilated biomass in the soil in a stable form. That stable form of organic matter can be none but biochar. Biochar has a great capacity to sequester carbon for hundreds of years. Besides carbon sequestration, it has excellent adsorption capacity among many other soil enhancing properties. This adsorption capacity gives biochar the ability to sorb many bad things responsible for climate change including GHGs and soil and water pollutants. Reports has it that biochar efficiently reduces carbon dioxide emissions from decaying organic matter, nitrous oxide emissions from extensively fertilized fields and methane emissions from inundated soils. The excellent adsorption capacity of biochar does not stop here and many soil and water pollutants are adsorbed to biochar and hence locked in the soil for an indefinite time. This adsorption capacity keeps biochar for another great service to humanity due its use in renewable energy production systems. Fuel cell systems that are considered as clean energy sources make use of biochar as a storing material, a catalyst, and as cathode in clean batteries. In anyway, biochar, although not alone, can be used as a remedy for climate change.

However, biochar production may also happen at the expense of greenhouse gas emissions. It is upon scientific community to develop techniques of biochar production that are environment friendly. A regulatory framework could be developed and incorporated into guidelines which would allow for the production and application of only those biochars which are effective for soil health, increase productivity and contribute positively towards climate change.

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Chapter 9
Biofortification Under Climate Change: The Fight Between Quality and Quantity

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Abstract Climate change has been a serious problem in our industrialized world for the last century. We have faced its devastating effects on the environment, agriculture and human population. In current scenarios, around 3.8 billion people are predicted to live in areas with severe water problems by 2025. As the majority of staple crops are sensitive to environmental fluctuations, only an increase in global temperatures by 2 °C can disrupt agricultural practices and crop production periods severely. Therefore, plant breeders have canalized all the efforts to enhance the grain yield and produce more crops under adverse environmental conditions to meet the demand of the ever-increasing human population. However, the majority of current staple crop varieties produce grains with insufficient micronutrients. Moreover, climate change decreases micronutrient uptake from the soil and translocation within the plant body. In this chapter, three strategies (agronomic, breeding and transgenics) of micronutrient biofortification in various staple crops are explained with recent successful examples.

Keywords Abiotic stress · Agronomy · Breeding · Biofortification · Climate change · Genetic engineering

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_9

9.1 Introduction

Most of the food scientists around the world are not exclusively focused to enhance food quantity but also centralized their attention to the quality, keeping in view the scenario of population explosion and nutritional demands of human beings and animals. In the past 50 years, research in agriculture has met Malthus's challenge by increasing production as its central aim. However, the question arises, whether an increase in food quantity is enough to fulfill the demand for a healthy life. In the case of food, quality can be defined as the size, color, gloss, shape, taste, and nutritional value (density of vitamins and nutrients in the crop plants). In most of the developing countries, the main focus of research is to produce calorically dense staple crops, but the production of micronutrient-rich non-staples (i.e., vegetables and pulses) has not augmented in equal amount (Bouis and Saltzman 2017). No need to mention that non-staples are the commonly used food commodities in many countries of the world.

Human beings require 49 nutrients in order to carry out their metabolic activities in a proper way. Deficiency of even one nutrient can cause retarded growth, sickness and impaired growth in children (Welch and Graham 2004). According to an estimate, more than half of the world's population is afflicted by micronutrient malnutrition (Shukla and Mishra 2018). According to WHO (World Health Organization), micronutrient malnutrition is one of the major causes of human mortality around the globe, which accounts for more than 20 million people per annum (WHO 2009). It is estimated that about 60% of the world's population is iron deficient and 30% is either zinc or iodine deficient. Moreover, magnesium, copper, and calcium deficiencies are common in most of the developing countries (White and Broadly 2009). Moreover, 50% of the world's population is affected by different vitamin deficiencies (Naqvi et al. 2009). Around one-third of preschool-age children and about 15% of the pregnant women are anticipated as just vitamin A deficient (WHO 2009). These nutrients and vitamins can be provided by the intake of a variety of food products in a diet consisting of fruits, vegetables, cereals and pulses since plants are the absolute source of the human diet. However, the availability of various food products is often limited to the poor people, especially in developing countries. Therefore, there is a need to produce biofortified staple crops. Biofortification of staple food crops with micronutrients and vitamins is one of the painstaking challenges for agricultural scientists at present and it will be more and more important in the coming decades (Fig. 9.1).

Biofortification can be defined as increasing the vitamin and mineral contents in crop plants via conventional (plant breeding and agronomic techniques) and non-conventional means (genetic engineering) (Hirschi 2009; Bouis et al. 2011). The actual 'health comes from the farm, not from pharmacy' is at the heart of ongoing biofortification programs (Bouis and Saltzman 2017). Micronutrient malnutrition is also known as the hidden hunger affecting both animals and humans. Hidden hunger or micronutrient deficiency retards the growth and development of both plants and humans (Sanchez and Swaminathan 2005). As plants are the primary source of

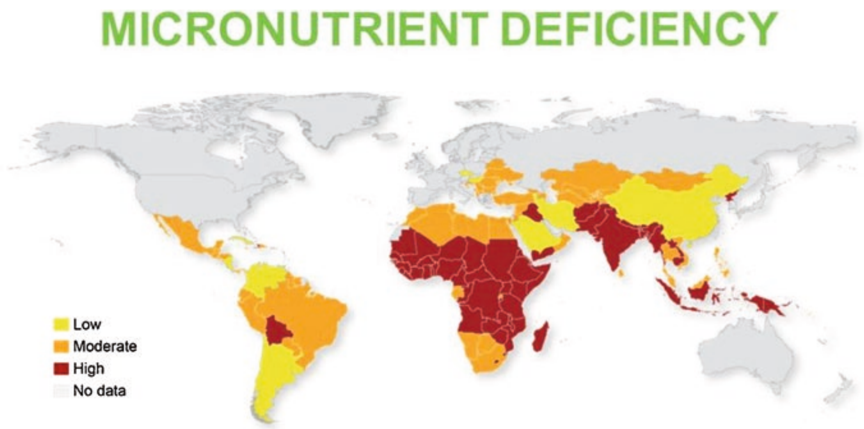

Fig. 9.1 Hidden hunger and stunting, or impaired development, are typically associated with poverty and diets high in staple crops such as rice or maize. Biofortification of essential nutrients into these staple crops has the potential to reduce malnutrition and micronutrient deficiencies around the world. This map details worldwide severity of the most common micronutrient deficiencies – vitamin A, iron, and zinc – using World Health Organization (WHO) children under 5 prevalence data. Severity was coded using a 3-point weighting system based on levels of public health significance cut-offs (low, moderate and high). (Source: CIMMYT Global Maize Program)

food, soil micronutrient deficiencies limit crop productivity and nutritional quality of foods, which together affect human nutrition and public health.

Our crop breeding system has canalized all the efforts to enhance the grain yield and produce more crops to meet the demand of the ever-increasing human population. However, many staple crop species that are used in the present agriculture produce grains with micronutrient deficiencies since there is a negative correlation between the grain size and yield with nutritional quality. This is one of the major reasons that lead to human malnutrition. With the scientific developments in crop biofortification, now agriculture is in a transition from producing more quantity of crops to producing nutrient-rich crops in sufficient quantities. This will support us to raise and fight against hidden hunger particularly in developing countries, where micronutrient-poor staple food crops dominate diets.

Climate change is a fact that humanity needs to face within the near future in terms of crop production, malnutrition, food insecurity, and public health (Fahad and Bano 2012; Fahad et al. 2013, Fahad et al. 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). The future predictions of crop production are overwhelmingly a vexing problem. Change in environmental conditions causes abiotic stresses such as high temperature, drought, cold, salinity, and flooding (Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamaran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017). All these conditions lead to oxidative stress that triggers the production of reactive oxygen species. The stress conditions destroy cell integrity, biochemistry, plant physiology, and morphology. Eventually, the sensitive plants cannot survive and diminish while the tolerant ones continue their life cycles under abiotic stress conditions. Climate change not only leads to abiotic stresses but also influences the biotic stress conditions, including pathogens, insects, nematodes, and pests, which in turn cause devastating problems in the field and diminish the crop production. Although the crop breeders, scientists, and agriculture research entities mainly focused their efforts on the development of stress-tolerant crops with high yields in the last 100 years, stress conditions also decrease the crop nutritional value. Therefore, more research is needed to develop new crop varieties that are tolerant to stress conditions with high yield and nutritional quality.

9.2 Effect of Climate Change on Crop Yield

In the current scenario, world temperature is increasing day by day due to large emission of greenhouse gases such as methane, carbon dioxide, chlorofluorocarbons (Misra 2014). Keeping in view the climate change, agricultural researchers are focused on the impact of environmental changes on crop production. However, in recent years, climate change has received more attention from national and international bodies, non-government organizations, corporations and at individual level as well. Moreover, Mr. Barrack Obama, (44th President of the United States of America) also gave a statement that climate change is not a big problem rather it is a challenge for us (The Straits Times 2019). According to a report in 2000, 1.8 billion people lived in areas with severe water scarcity (Vörösmarty et al. 2000). Using a global water model integrating the changes in population, climate and economic conditions, it was concluded that the human population in areas with severe water problems would have increased to more than 2 billion by 2025. Now, we only are 6 years before the predicted date and already see a more pressure on human populations due to speeding extent of climate change.

Regarding climate change, agriculture is the focus because of the direct interaction of crops with climate. Climatic conditions like air and soil temperature have a greater influence on crop growth and development. Climate change has also increased the rate of climate-related disasters, i.e. floods and droughts. They have an adverse influence on crop production and food security. Global temperature rise has resulted in floods due to increasing sea levels caused by the melting of glaciers and the extension of oceans (Kibria 2016).

Climate change is not only the result of increasing mean annual air temperature but also the increase in the concentration of greenhouse gasses in the atmosphere (IPCC 2007). Over the past 100 years, the global increase in mean annual temperature is 0.74 °C. The frequency of climate events such as floods and droughts has also been enhanced by climate change. Due to an increase in temperature, Gangotri glacier, one of the Himalayas largest glacier is deteriorating around12–13 m annually (Misra 2014), which will result in flooding at the end. The impacts of these changes on crop production and on food safety are adverse. The increase in sea-level rise

(SLR) affects food security and food production, as the increase in sea levels can lead to saltwater intrusion into crop fields and freshwater (Kibria 2016). When crops are submerged into floodwater, sea-level rise may cause the failure of crops due to blockage of soil aeration. Saltwater intrusion can also contribute to saline and waterlogged soils, which leads to land degradation, thus making the soil unfit for cropping. In Bangladesh, it has been discovered that an SLR of 1.5 meters may flood about 16% area of the country (which is suitable for rice cultivation) (Kibria 2016). Thus, it will affect rice production.

Moreover, the majority of staple crops are sensitive to fluctuations in temperature and precipitation. An increase in global mean temperatures by 2 °C can disrupt agricultural practices and crop production periods (Kang et al. 2009). While for annual crops that have the determinate type of growth habit, a rise in mean seasonal temperature of 2–4 °C can reduce the yield up to great extent (Wheeler et al. 1996; Betts et al. 1997). Because this increase in temperature can decrease the crop growth period.

In a consequence, increase in temperature will affect the crop production period, rainfall patterns, hydrological cycle, cultivar selection, quality and quantity of food crops (Aerts and Droogers 2004). On the other hand, climate change is also affecting the groundwater level and air temperature. Reduction in water resources and the rise in average air temperature happened globally in the last some years. These unsuitable conditions and fluctuations in the climate will lead to a decrease in crop production (Rosenzweig and Liverman 1992; McCarthy et al. 2001). Most probably change in climate conditions year to year is one of the most substantial factors affecting crop production, even in high-yield and high-technology agricultural areas.

Another impact of climate change is the increase of greenhouse gases in the environment, i.e. increase in carbon dioxide. It has been hypothesized that by 2100, CO_2 concentrations will increase from present atmospheric levels of about 385 ppm to about 500–1000 ppm (Taub 2010). Some scientist's assumed that elevated concentrations of atmospheric CO_2 are useful to the plant's physiology, development, and chemistry. It has been claimed that increase in CO_2 concentration by two fold will lead to a 10–15% increase in dry matter content, if all other agronomic practices will be kept constant (Santra et al. 2014). The reason behind this prediction is that more concentration of CO_2 will enhance the photosynthetic rate, which ultimately enables the crop to produce more glucose for a number of processes. However, it is essential to know that the advantages of enhanced concentrations of CO_2, as stated are only advantageous if it is independent of any other impacts of climate change such as increasing global temperature. Researchers at Stanford University found that high CO_2 levels in the presence of other climate change impacts decreased the plant growth and nutrient status (Schwartz 2012).

Effect of climate change on yield is determined by the species. Some will see the highest pressure while the others will be affected less, and even some crop species will be affected in a positive way in short term. For instance, for a long time C4 plants were believed to be less affected negatively, or even positively affected by increasing atmospheric CO_2 levels (Ehleringer and Björkman 1977; Ehleringer et al. 1997). This theoretical prediction was supported experimentally leading to a fact that the growth and yield of C3 crops are more limited than do C4 crops under current CO_2 levels. This suggest that C3 plants will be affected negatively more than C4 plants from increasing CO_2 levels and climate change. However, all prediction models depict a high level of yield loss in all of stable food crops, which will hinder the total crop production and lead to food insecurity, hunger and poverty. Interestingly, a contrasting evidence to this C4-elevated CO_2 theory was demonstrated recently (Reich et al. 2018). The researchers analyzed the biomass of C3 and C4 grasslands under ambient and elevated CO_2 levels (an additional 180 ppm CO_2) for 20 years in Minnesota, USA. The results showed that the biomass was significantly increased at high CO_2 compared to ambient CO_2 in C3 but not C4 grasslands for the first 12 years of the experiment. However, the pattern was reversed in the next 8 years, where the biomass of C4 increased whereas C3 was not. This pattern change was attributed to the nitrogen mineralization in the soil, which determines the total nitrogen supply to the plants.

Climate change could sturdily affect the wheat yield, which accounts for 21% of global food, cultivated on 200 million hectares around the world. Although global warming may be helpful in the coming years for wheat production in some regions where temperature is low, it will be harmful for some regions where optimal temperature always exists. High temperature will decrease seed yield, so it is vital to develop some heat-tolerant wheat germplasm to handle the yield loss by climate change (Ortiz et al. 2008). Analysis of maize yield in precise irrigation in Bulgaria for 30 years determined that the average yield will be lowered by 60% in a season with low precipitation (Popova and Kercheva 2005). Effects of climate change on rice yields in Volta Basin in Mali was predicted by different models to increase 45–30% depending on the scenario (Droogers et al. 2004). Increasing temperature and CO_2 levels are predicted to enhance the rice yields in normal irradiation paddies in Eastern India (Krishnan et al. 2007); however, high temperatures can cause spikelet sterility and a shift in sowing time. In another model, cereal and soybean yields were predicted to increase at high and mid-latitudes whereas a major decrease was expected at lower latitudes (Parry et al. 1999). Similar results were obtained in different prediction models (Reddy and Pachepsky 2000). When climate effects are compared between the period of 1961–1990 and 2071–2100, it was very obvious that the increasing temperature will not have been the key factor determining the crop yields, but extreme temperature anomalies would have a more pronounced effect on crop yields even under irrigated conditions (Challinor et al. 2007).

Furthermore, increasing global temperatures have also led to the desertification phenomenon to dry up water bodies. Desertification contributes to the loss of arable land due to the shortage of water, resulting in the hardening of the land, which makes it unsuitable for the cultivation of crops or animal husbandry. Clearly, climate change influences water considerably as it not only changes physical and chemical circumstances (e.g. acidity and oxygen content) within water bodies but also changes bio-environment, i.e. the decrease in marine life, reallocation of the distribution and abundance of marine species (Cheung et al. 2015). The lack of water for cultivation will lead to the death of crops. It is reported that in the year 2003 due to climate change, maize yield has decreased significantly in some

European countries i.e. Italy (36% decrease) and France (30% decrease). Moreover, increasing global temperatures induced by climate change could lead to an increase in weed growth and development. Consequently, it will enhance the use of herbicides (Islam and Wong 2017).

With the expected increase in temperature in the future, plants are more susceptible to the intensive attack of insect-pest and plant diseases (Santra et al. 2014). This is because of increasing temperatures usually generate more ideal circumstances for disease-causing bacteria and pests, which can adversely influence crop development, quality, and quantity (Santra et al. 2014). Deutsch et al. (2018) reported that an increase in temperature causes the increase in insect's metabolic rates, more yield losses in crops are expected by insect attacks in the future, suggesting the farmers will be forced to use more synthetic insecticides and pesticides in the field.

Because of the above-mentioned intimidations related to climate change, world agriculture production is on threat and it will create food insecurity for the upcoming generations especially in developing countries where the poor will suffer greatly as they are unable to pay the upmarket prices for food.

9.3 Effect of Climate Change on Plant Nutrient Uptake

Nutrient acquisition and translocation in plants is affected by various abiotic stresses. Abiotic stress is defined as environmental factors that affect the plant growth and development which results in yield loss and poor nutritional quality of crop. Plant abiotic stress factors include high temperature, water scarcity and logging, nutrient deficiency and toxicity (Andjelkovic 2018). As mentioned above, it is predicted that the global temperatures will be higher and water scarcity will be dominant in the future which will affect the nutrient uptake and crop yield due to climate change in the world.

Iron is one of the most essential micronutrients involved in a number of metabolic processes, including photosynthesis and respiration. Any defects (deficiency or toxicity) in iron mobilization cause severe yield losses in crops. Thus, iron homeostasis in plants must tightly be regulated for proper growth and development of plants (Gao et al. 2019). Although the amount of iron in the soil is high, it is unavailable to the plants because of high soil pH, which is the major hindrance in iron uptake in plants (Aksoy et al. 2017). Despite of high pH, high temperature also causes the reduction in iron uptake by the plants. Rivero et al. (2003b) reported that tomato and watermelon plants have shown less iron uptake and reduced FeCH-R activities. On the other hand, as we know that CO_2 is one of the most important greenhouse gases causing the global warming. When tomato plants were grown under high CO_2 (800 μL L^{-1}) conditions they have showed more root and shoot iron content as compared to the plants grown under ambient CO_2 concentration (350 μL L^{-1}) (Jin et al. 2009).

Moreover, the high temperature have adverse effects on zinc acquisition in plants. It is reported that with rise in temperature, Zn uptake decreases, which ultimately results in low yield and poor nutritional quality of the crop (Raj et al. 2015). In addition, increase in temperature can alter the uptake of nitrogen and phosphorus as well in plants (Kumar 2011). Interestingly, it is reported from previous study that an increase in temperature enhances the phosphorus uptake and translocation in wheat under heat stress (Manoj et al. 2012). Moreover, Jin et al. (2006) have reported that phosphorus uptake and accumulation increased in soybean under water stress.

High temperature stress can also decrease the enzymatic activities responsible for nutrient metabolism (e.g. ammonium and nitrate absorption) (Klimenko et al. 2006; Hungria and Kaschuk 2014). Low nutrient uptake due to high temperature stress might be due to different factors, such as reduction in rhizosphere or nutrient acquisition per unit root (Bassirirad 2000; Giri et al. 2017). The above-mentioned decrease in nutrient acquisition per unit root may be due to the reduction of labile carbon (total non-structural carbohydrates). This reduction in overall carbohydrates in the roots might occur due to a reduction in translocation of carbohydrates from the shoot towards the root or due to enhancement in root respiration. It can even be caused by direct root damage due to high temperature stress (Huang et al. 2012), which may affect the formation and functionality of nutrient acquisition proteins.

As explained above, climate change will create drought in many areas of the world in the future. Besides affecting the yield, drought also affects the nutritional quality of the crop by decreasing the efficiency of nutrient uptake. In plants, most of the nutrients uptake from the soil to the roots is dependent upon the amount of water present in the soil. Moreover, nutrient immobilization between roots to shoots is also decreases under drought because of a decrease in transpiration rate in the plants and imbalance active transport and membrane permeability (Silva et al. 2011). Drought reduces the diffusion rate of nutrients in the soil towards the roots, root nutrient uptake, and then translocation into the shoot due to associated decrease in transpiration flux, active transport and permeability of the membrane (Hu and Schmidhalter 2005). With the help of multi-elemental analysis, drought effect on nutrient composition of the seed among various plant species was demonstrated to be severe (percent reduction in grain yield) or moderate. Significant reduction in seed yield is thought to be due to severe drought than the moderate one. The seed composition of macronutrients and occasionally Ca were reduced (or remain intact) by severe drought. Drought have variable effects on Zn, Fe, Mn or Cu uptake and translocation (Etienne et al. 2018). Drought increases the leaf Mn and Cu content while it decreases the Fe content in the leaves. It is hypothesized that the increase in leaf Mn content is due to higher need of Mn superoxide dismutase, which participates in the ROS detoxification under drought stress. (Acosta-Gamboa et al. 2017). All these consequences cause poor plant growth and yield losses. A proper understanding of nutrient uptake and translocation under various abiotic stresses can be helpful to develop strategies to reduce the harmful effects caused by abiotic stresses and disturbed nutrient homeostasis (Silva et al. 2011).

Field observations and greenhouse studies by Huang et al. (2005) have shown the relationship between boron deficiency and leaf injury due to low temperature stress in plants, but the reason behind the relation of these two stresses at molecular, biochemical and physiological stages have yet to be explained. Partial evidence explains that low temperature in the rhizosphere restricts B uptake capacity and B supply/use efficiency in the shoots. This interaction is based on low temperature tolerance of the respective species, the nature of low temperature treatment (sudden versus steady temperature decline) and growing environmental conditions (e.g. photon flux density and relative humidity) that may promote the low temperature stress. Antioxidant activities of plants can be increased by efficient boron uptake and thus, alleviate the damage caused by ROS induced by low temperature stress. Boron uptake enhances sugar transportation in plants, which ultimately improve seed germination and grain formation. Thus, it can recover the yield by decreasing the effect of low temperature (Waraich et al. 2012).

The amount of water present in the soil can affect iron homeostasis in the plants. As in wet soils, the Fe^{2+}/Fe^{3+} ratio is higher, which results in more iron availability or uptake by the plants. On the other hand, more presence of oxygen under drought conditions causes a reduction in Fe^{2+}/Fe^{3+} ratio leading to lower iron availability to the plants (Sardans et al. 2008). Furthermore, it is reported that drought also reduces the nitrogen and phosphorus uptake in plants (Bista et al. 2018).

9.4 Agronomic Biofortification Strategies and Success Stories

The main long-term goal of biofortification is providing nutritious, healthy, safe food in a sustainable, affordable and sufficient way to the entire global human population (Saltzman et al. 2013). There are three ways of biofortification of food crops with essential micronutrients. The first one is the agronomic biofortification that includes the integration of fertilizers into agriculture production. The second way is the conventional or genetic crop breeding that includes the enhancement of mineral levels in the grain or seed with help of conventional and molecular breeding methods. The third biofortification strategy is the transgenics that involves the generation of new crop varieties through genetic engineering and recent genome editing technologies (Garg et al. 2018). By using these strategies, various staple food crops including wheat, maize, rice, barley, potato, pulses and tomato have been biofortified with different micronutrients (Garg et al. 2018) (Table 9.1).

Agronomic biofortification means physical application of fertilizers and other agronomic practices to ameliorate the nutrient acquisition and storage in crop plants (Cakmak et al. 2017). Usually macronutrients such as nitrogen, phosphorous and potassium in appropriate amount makes positive contributions in increasing crop yields. Through the application of NPK (Nitrogen, Phosphorous and Potassium), the yield of many crops had increased up to great extent and resulted in Green Revolution in 1960s by saving millions of people from starvation (Erisman et al. 2008). In the current scenario, application of these macronutrients is

Table 9.1 Biofortified crops by the means of transgenic, agronomic and breeding approaches at present

Name of crop	Type of biofortified nutrient	Approached used for Biofortification	Present status of biofortified crops with country and varieties
Rice (*Oryza sativa*)	Iron	Transgenic	Under research
		Agronomic	Under research
		Breeding	Released
		Breeding	Under research
	Beta-carotene, Phytoene (precursor of beta-carotene)	Transgenic	Under research
	Phytic acid (iron bioavailability	Transgenic	Under research
	Zinc	Transgenic	Under research
		Agronomic	Under research
		Breeding	Released
		Breeding	Under research
	Folate (vitamin B9)	Transgenic	Under research
	High amino acids and protein content	Transgenic	Under research
	Alpha-linolenic acid	Transgenic	Under research
	Se	Agronomic	Under research
	Flavonoids and antioxidants	Transgenic	Under research
	Resistant starch	Transgenic	Under research
	Human lactoferrin	Transgenic	Under research
Wheat (*Triticum aestivum*)	Iron	Transgenic	Under research
		Agronomic	Under research
		Breeding	Released
		Breeding	Under research
	Provitamin A Carotenoids	Transgenic	Under research
	Phytase or phytic acid	Transgenic	Under research
	Amino acid composition	Transgenic	Under research
	Anthocyanin	Transgenic	Under research
	Amylose content	Transgenic	Under research
	Zinc	Agronomic	Under research
		Breeding	Released **India:** BHU 1, BHU 3, BHU 5, BHU 6, BHU 17, BHU 18 **Pakistan:** NR 419, 42, 421, Zincol
		Breeding	Released **India:** WB2
		Breeding	Released **India:** PBW1Zn
		Breeding	Under research
	Se	Agronomic	Under research
	P fertilizer + mycorrhiza	Agronomic	Under research
	Organic + chemical fertilizers (iron)	Agronomic	Under research
	Bacillus aryabhattai (zinc)	Agronomic	Under research

(continued)

Table 9.1 (continued)

Name of crop	Type of biofortified nutrient	Approached used for Biofortification	Present status of biofortified crops with country and varieties
	Carotene	Breeding	Released **India:** HI 8627
	Lutein	Breeding	Under research
	Anthocyanins (colored wheat)	Breeding	Released **China:** Black-grained wheat
		Breeding	Released **Austria:** Indigo
		Breeding	Registered **Slovakia:** PS Karkulka
		Breeding	Registered **India:** NABIMG-9, NABIMG-10, NABIMG-11
		Breeding	Under research
Maize (*Zea mays*)	Pro-vitamin A, Carotenoids	Transgenic	Under research
	Vitamin A (Orange Maize)	Breeding	Released **Zambia:** GV662A, GV664A, GV665A **Nigeria:** Ife maizehyb-3, Ife maizehyb-4, Sammaz 38 (OPV), Sammaz 39 (OPV) **Ghana:** CSIR-CRI Honampa (OPV)
	Vitamin E	Transgenic	Under research
	Vitamin C	Transgenic	Under research
	Multivitamin	Transgenic	Under research
	Phytase, ferritin (iron bioavailability)	Transgenic	Under research
	Phytate degradation	Transgenic	Released **China:** BVLA430101
	Lysine Lysine and tryptophan Methionine	Transgenic	Under research
	Lysine	Transgenic	Released **Japan, Mexico:** Mavrea™ YieldGard Maize **Australia, Columbia, Canada, Japan, Mexico, New Zealand, Taiwan, USA:** Mavera™ Maize – LY038

(continued)

Table 9.1 (continued)

Name of crop	Type of biofortified nutrient	Approached used for Biofortification	Present status of biofortified crops with country and varieties
	Lysine and Tryptophan (QPM)	Breeding	Released **India:** CML176, CML176 × CML186, HQPM-1, HQPM4, HQPM-5, HQPM-7, VivekQPM-9, FQH-4567, **China:** CML140, CML194, P70 **Vietnam:** CML161 × CML165, **Mexico:** CML142 × CML176, CML142 × CML150, CML176, CML170, CML186 × CML149, CML176 × CML186, **South Africa:** QS-7705 **Ghana:** GH-132–28 **Guinea:** Obatampa **Benin:** Obatampa **Uganda:** Obangaina **Mozambique:** Susuma **Brazil:** BR-451, BR-473, **Venezuela:** FONAIAP **Peru:** INIA, **Colombia:** ICA **Honduras:** HQ-31 **El Salvador:** HQ-61 **Guatemala:** HB-Proticta, **Nicaragua:** NB-Nutrinta, HQ INTA-993
	Human lactoferrin	Transgenic	Under research
	Zinc	Agronomic	Under research
	Se	Agronomic	Under research
	Plant growth-promoting rhizobacteria + Cyanobacteria (zinc)	Agronomic	Under research
	Provitamin A carotenoids Total carotenoids	Breeding	Under research
	Carotenoids, vitamin E and phenolic compounds	Breeding	Under research
	Anthocyanins	Breeding	Under research
	Fatty acids + vitamin E Research	Breeding	Under research

(continued)

Table 9.1 (continued)

Name of crop	Type of biofortified nutrient	Approached used for Biofortification	Present status of biofortified crops with country and varieties
Barley (*Hordeum vulgare*)	Zinc	Transgenic	Under research
	Phytase	Transgenic	Under research
	Lysine	–	–
	Beta-glucan	Transgenic	Under research
	Resistant starch	Transgenic	Under research
	Polyunsaturated fatty acids	Transgenic	Under research
	Human lactoferrin	Transgenic	Under research
	Biofertlizers + NPK fertilizers + Vermicompost	Agronomic	Under research
Sorghum (*Sorghum bicolor*)	Provitamin A	Transgenic	Under research
	Lysine	Transgenic	Under research
	Improved protein digestibility	Transgenic	Under research
	Mycorrhiza + Bacteria	Agronomic	Under research
	Farmyard manure + biofertilizer	Agronomic	Under research
	Iron	Breeding	Released **India:** ICSR 14001, ICSH 14002 **Hybrids:** ICSA 661 × ICSR 196, ICSA 318 × ICSR 94, ICSA 336 × IS 3760
		Breeding	Released **Nigeria:** 12KNICSV (Deko)-188 12KNICSV-22(Zabuwa)
	Iron, zinc, beta-carotene	Breeding	Under research
Foxtail millet (*Setaria italica*)	Iron and zinc(Pearl Millet)	Breeding	Released
	Iron and zinc	Breeding	Under research

necessary to obtain higher crop yields. Additionally, plants absorb micronutrients (iron, zinc, copper, manganese etc.) from the soil and usually accumulate in their edible parts (Graham et al. 2007). Plants can only uptake specific form of these nutrients from soil, however different agro-ecological zones have different soil conditions (i.e. high or low pH, salt accumulation, different oxidative form of nutrients and their complexes with other substances), which create difficulties in the proper nutrient uptake by plants. In this regard, micronutrient fertilization through soil or by foliar means can contribute to diminution in micronutrient deficiency problems in the human beings by increasing nutrient uptake and accumulation in the plant's edible parts. Besides synthetic fertilizers, application of different beneficial microorganisms and fungi (such as *Rhizobium*, *Bacillus*, *Azotobacter*, *Pseudomonas* and abuscular mycorrhizal fungi – AMF) have been tested to demonstrate their efficient usage in elimination of mineral deficiency symptoms in plants by increasing the phytoavailability of micronutrients and enhancement of micronutrient accumulation in edible parts of the crops (Prasanna et al. 2016). More nutrient uptake by the crop plants and loading in the edible parts is the heart of current ongoing agronomic biofortification research programs. These programs have shown to be very successful in increasing the mineral levels in edible parts of the crops and changing the daily-lives of millions (Garg et al. 2018). Recent advances in agronomic biofortification of some major crops are discussed in this section.

9.4.1 Agronomic Biofortification of Rice

Biofortification of micronutrient in rice through the common agronomical practices is regarded as crucial and alternative for the alleviation of nutritional deficiencies related with iron and zinc in rice. Spray of iron-containing compounds in the leafy portion of rice plants was effective enough to enhance iron content in rice grain (Fang et al. 2008; He et al. 2013; Yuan et al. 2013). In a same manner, a remarkable achievement was ensured enhanced iron content (more than 15.6 times compared to the control) in brown rice through the fortification of germinating rice plants with ferrous sulfate (Yuan et al. 2013). Recently, for the development of rice variety with elevated content of zinc and its bioavailability (Fang et al. 2008; Wei et al. 2012a, b; Boonchuay et al. 2013; Jiang et al. 2008; Mabesa et al. 2013; Shivay et al. 2008; Ram et al. 2016), external application of zinc in rice leaves has been recorded as an efficient agronomic effort. Besides the above, exogenous implementation of zinc to the soil having low background levels of zinc improved zinc content in the grain (Guo et al. 2016). In rice, foliar application of zinc is reported to be an effected method of biofortification as in rice plants Zn concentration had increased up to 25% and 32% by foliar and foliar + soil applications, respectively, whereas only 2.4% increase was observed by soil Zn application (Phattarakul et al. 2012). Selenium is an imperative micronutrient for both plants and animals because of its antioxidant activities. Research showed that soil application of selenium had increased yield and selenium accumulation in the rice seeds (Boldrin et al. 2013). Furthermore, zinc deficiency is one of the major problems in human beings. Rice with increased selenium (essential trace element and potent antioxidant for human health) has been developed by the foliar spray of selenate as a fertilizer in rice (Fang et al. 2008; Chen et al. 2002; Ros et al. 2016; Premarathna et al. 2012; Xu and Hu 2004; Giacosa et al. 2014; Liu and Gu 2009). In addition, complex application of iron and boron by foliar means have the capability to biofortify the rice, as it is reported that compared to control, iron concentration in the rice seeds was significantly increased up to 18.9% by the foliar application of Fe(II)-AA and boron. Moreover, Fe (II)-AA and B application has increased Zn concentration up to 26.7%, and amino acids such as lysine and arginine, which are important for human nutrition, have increased up to great extent (Jin et al. 2008).

9.4.2 *Agronomic Biofortification of Wheat*

Foliar spray of zinc sulphate ($ZnSO_4$) fertilizer has significantly increased the yield and grain zinc content in the wheat crop (Cakmak et al. 2010). Application of zinc fertilizers can decrease the zinc micronutrient deficiencies in the humans, especially in those regions where the zinc deficient soil prevails. In the rural areas of the Turkey where 50% of the daily diet depends upon wheat Zn fertilizers has definitely improved the zinc nutrition in humans (Cakmak 2008). Field experiments carried out for 8 years in 12 countries on wheat demonstrated clearly that soil Zn applications at the time of sowing had little effect on Zn accumulation in grains while foliar Zn applications were very effective in enhancing the grain Zn levels (up to 83%) (Cakmak and Kutman 2018). These results are affected by the time of foliar fertilizer application (Welch et al. 2013), being more effective especially at grain-filling stage (Boonchuay et al. 2013; Abdoli et al. 2014). Moreover, inoculation of *Bacillus aryabhattai* strains in the wheat has reported to increase the zinc content in the edible part of the crop (Ramesh et al. 2014). In a recent study conducted in six different countries including Turkey, Pakistan, Mexico, India, China and South Africa, foliar application of cocktail spray of fertilizers containing iodine, selenium, zinc and iron has significantly increased the accumulation of iodine (from 24 μg kg^{-1} to 249 μg kg^{-1}), selenium (90 μg kg^{-1} to 338 μg kg^{-1}), zinc (28.6 mg kg^{-1} to 47.1 mg kg^{-1}) and iron (up to 12%) in wheat grain (Zou et al. 2019). Thus, agronomic biofortification of wheat crop through these fertilizers can be one of the possible cures to overcome the problem of micronutrient deficiencies in humans and yield losses in crop plants lead by nutrient unavailability.

Agronomic means of biofortification has been utilized effectively in wheat for the improvement of grain quality and foliar urea fertilizers with iron showed positive correlation with high accumulation of iron (Aciksoz et al. 2011). Reduction of anti-nutrient factors (phytic acid) in wheat improved its bioavailability and soil with potentially zinc-deficient was capable to reduce human zinc deficiency with exogenous supply of foliar zinc (Yang et al. 2011). Furthermore, iodine is an important component of the hormones secreted by thyroid glands and deficiency of it causes the problems with the thyroid glands in humans (Eastman and Zimmermann 2018). Cakmak et al. 2017 had reported that the foliar application of KI and KIO_3 during the heading and the early milk stage in the wheat crop has increased the iodine accumulation in the wheat grains up to ten-folds with constant yield. Successful biofortification of Se in wheat was documented in Finland (Aro et al. 1995) and simultaneous application of compound fertilizers supplemented with selenium revealed increased amount in human serum. Beside the chemical and organic fertilizers, the utility of bio-fertilizers in enhancing the grain yield was excluded and combinations of fertilizers and fungal components of mycorrhizal origin were used proficiently for the biofortification (Nooria et al. 2014). In another study, soil application of *Providencia* sp. together with NPK enhanced the grain protein content up to 18.6%, whereas it enhanced the levels of Zn, Fe, Mn and Cu in the grain by 135.0, 105.3, 36.7 and 150.0%, respectively (Rana et al. 2012). Biofortified wheat with combined utilization of organic and chemical fertilizers manifested with high grain quality (Ramzani et al. 2016; Ramesh et al. 2014).

9.4.3 Agronomic Biofortification of Maize

Deficiency of micronutrients including selenium, zinc and iron is a major concern especially in the African countries where majority of population does not have access to a variety of food products in order to fulfill their nutrient requirements. Maize is a major crop used around the globe. To avail nutrient-enriched crop grain and sustainable yield in maize, zinc is one of the prerequisite and zinc-enriched maize was developed through several treatment with zinc fertilizer and foliar applications (Alvarez and Rico 2003; Fahad et al. 2015; Wang et al. 2012; Zhang et al. 2013). Rhizobacteria responsible for plant growth and development has a crucial role for the nutritional enrichment of maize crop and agronomic practices important for the biofortification of staple crops, especially maize with improved zinc content (Prasanna et al. 2015). As an efficient tool of agronomic biofortification, exogenous supply of fertilization ensure elevated content of selenium in maize that is essential for human and animal health promotion (Ros et al. 2016). In Kenya, soil and foliar application of selenium has increased the selenium accumulation by an average of 3 μg kg^{-1} and 18 μg kg^{-1} in the maize grains (Ngigi et al. 2019). According to a study done in Malawi, it was predicted that an application of 5 g Se ha^{-1} to maize crops via foliar spray would increase dietary Se intake by 26–37 μg Se per person per day (Chilimba et al. 2012).

9.4.4 Agronomic Biofortification of Barley and Sorghum

Biofortification of barley has added a new dimension in micronutrient profile, especially zinc and iron content by the application of several inorganic and organic biofertilizers along with vermicomposting (Maleki et al. 2011).

Globally, cultivation of sorghum is suffering few crucial challenges due to poor nutritional status and contamination of soil that has been addressed to improve the yield quality with organic and chemical fertilizers. Up to date, through the combined utilization of growth-regulating bacteria and AMF (Patidar and Mali 2004; Dhawi et al. 2016) scientists are intend to enhance the nutritional content of sorghum. Beside these, inoculations of *Azospirillum* with phosphate-solubilizing bacteria in soil improved the soil fertility, especially phosphorous and nitrogen status that finally ensure the increased sorghum grain yield and protein content (Patidar and Mali 2004).

9.4.5 Agronomic Biofortification of Soybean

Soybean is an important commercial crop belongs to the leguminous family having production of millions metric tons every year. (Aksoy et al. 2017). Several soybean products are used by human beings, as well as it is an important part of animal feed in many regions of the world. Keeping in view of its extensive usage in animal dietary and its direct or indirect use by human beings make it one of the potential crops for biofortification. In China, selenium-enriched soybean has been produced by the foliar application of sodium selenite as the fertilizer (Yang et al. 2003). Soybean sprout is very popular food in the Southeast Asian countries. By the application of $ZnSO^4$, zinc content in the soybean sprouts was significantly increased, which can prove as a tool of zinc supplementation to overcome the problem of zinc deficiency in the population (Zou et al. 2014). Microbial transformation of unavailable soil zinc to the plant available zinc is an important approach to improve zinc acquisition in plants. A study published on soybean has reported that inoculation of *Bacillus aryabhattai* strains (MDSR7 and MDSR14) has increased plant zinc uptake and zinc accumulation in the seeds (Ramesh et al. 2014).

9.4.6 Agronomic Biofortification of Other Legumes

Chickpea is an important legume crop and its biofortification has been extensively studied by the application of various fertilizers and inoculation of chickpea with various bacterial strains. According to a study in India, zinc–ethylenediaminetetraacetic acid (Zn-EDTA) application from the foliage showed better results than zinc sulfate heptahydrate application from soil on Zn uptake and use efficiency, grain yield, Zn biofortification of grain in chickpea (Shivay et al. 2015). It is reported that inoculation of various strains of *Actinobacteria* has increased the assimilation of iron, zinc magnesium, manganese, calcium and copper in the chickpea seeds (Sathya et al. 2016). Furthermore, in Spain, foliar application of sodium selenate and sodium selenite has significantly increased the selenium concentration in the grain (Poblaciones et al. 2014). Moreover, application of a mixture of fungal inoculation (*Funneliformis mosseae* and *Rhizophagus irregularis*) increased the Fe and Zn levels in the seeds by 5 and 16%, respectively (Pellegrino and Bedini 2014).

Wahid et al. (2019) had reported that inoculation of arbuscular mycorrhizal fungi in mung bean grown on alkaline soils has increased the phosphorus uptake and accumulation by the application of composted cattle dung, supplemented with powder of rock phosphate.

Application of zinc sulphate from soil and foliage together was shown to enhance the seed Zn accumulation in pea (Poblaciones and Rengel 2016). Priming the pea seeds with solutions of iodine and selenium increased the biomass and the concentrations of both elements in the sprouts (Jerše et al. 2017). After treatment with iodine (I^- and IO_3^-) and selenium (SeO_3^{2-} and SeO_4^{2-}) in pea plants, I and Se contents increased more than 6- and 12-folds, respectively, in the seeds compared to the control plants (Jerše et al. 2018). Moreover, combined applications caused an increase in anthocyanins in plants. In order to ameliorate the negative effects of heat stress, application of Zn fertilizer in combination with humic acid and chitosan was shown to be successful in increasing the overall growth, yield and seed Zn biofortification in common bean under heat stress (Ibrahim and Ramadan 2015).

9.4.7 Agronomic Biofortification of Potato and Sweet Potato

Due to high yield potential and comparably better digestibility, potato biofortification is at the uttermost significance in agronomic biofortification. However, this is a major challenge as the mineral uptake and translocation to the tubers is difficult (White et al. 2012). Foliar Zn application was shown to double the tuber Zn content; however, there was a saturation limit in the yield (White et al. 2012). Moreover, the type of Zn fertilizer was found to affect the tuber Zn accumulation. Zinc oxide and zinc sulphate were more effective than zinc nitrate as foliar fertilizers without negatively affecting the yields (White et al. 2017). Zn bioavailability in tubers was increased up to 4 times by priming the tubers for 12 h in 10 mg mL^{-1} of $ZnSO_4$ (Vergara Carmona et al. 2019). Extended priming duration especially enhanced the Zn levels in the cortex of the tubers. Application of sodium selenate together with 0.15% of soluble leonardite as a source of humic acid markedly increased the tuber Se levels in potato (Poggi et al. 2000). In another study, Se-enrichment through fertilizer application was shown to enhance processing quality of potato tubers and Se accumulation in green tissues of plants that are developed from Se-enriched seed tubers even after 12 months of storage (Turakainen et al. 2006). In a hydrophonic experiment, the dose of 1.0 mg dm^{-3} of salicylic acid (SA) in combination with I and Se allowed the highest degree of accumulation of I in the tubers while the Se concentration was not affected (Smoleń et al. 2018). Interestingly, this experiment demonstrated that the application of SA together with I and Se affected the accumulation of other minerals in the tubers such that N, K and Na levels were increased while the Mn and Zn content was decreased.

Intermediate level (60%) of irrigation combined with appropriate dose of NPK fertilization was shown to enhance the β-carotene content up to 14% and yield up to 9.73 kg ha^{-1} in sweet potato (Laurie et al. 2012).

9.4.8 Agronomic Biofortification of Vegetables

Vegetables are the important part of daily food in most of the countries. In Brazil, selenium-biofortified carrots were produced by the foliar and soil application of two different sources of the Se (selenite and selenite) (Oliveira et al. 2018). Iodine (I^- and IO_3^-) and selenium (SeO_3^{2-} and SeO_4^{2-}) application from the soil was shown to enhance the accumulation of these minerals in the carrot; however, I^- and SeO_4^{2-} application negatively affected the glucose, total sugar and nitrate contents in carrot (Smoleń et al. 2016). Soil and foliar application of selenate and selenite increased the Se in the roots; however, the foliar application of selenate was the most effective source and form of application as it increased the reducing root ripening index together with the carotenoid content, yield and titratable acidity in carrots (Oliveira et al. 2018). In another study, combined application of Se and I increased the contents of each mineral in roots by 4.9-and 7.7-times, respectively (Smoleń et al. 2019).

In onion, foliar application of selenium is reported to increase the selenium assimilation up to 12.52- and 7.8-folds in onion bulb and vegetative part (Shafiq et al. 2019).

Greater Zn concentrations can be achieved in leafy vegetables because Zn transport in the phloem restrains Zn accumulation in other tissues (White and Broadley 2011). Brassicaceous vegetables including cabbage (*Brassica oleracea* var. capitata) and broccoli (*B. oleracea* L. var. italica) are among the most important vegetables in the world. In a 6 year of study, a linear relationship between Zn fertilizer application and shoot Zn concentration was observed in cabbage and broccoli at low application rates (White et al. 2018). Zn accumulation in the shoots was high enough to increase dietary Zn intake substantially and still was below the critical value that decreases the yield by 90%. In Indian mustard (*Brassica juncea* L.), sodium selenate application enhanced I accumulation by 2.64 times, while potassium iodide application increased the Se content by 4.3 times in plant leaves (Golubkina et al. 2018). Interestingly, combined application of both minerals did not affect the biofortification of neither minerals while significantly increasing the total soluble solids and ascorbic acid content in the leaves.

Higher efficiency of iodine and selenium biofortification of lettuce plants was shown after foliar application of Na_2SeO_4 and KIO_3 rather than through its introduction into the nutrient medium (Smoleń et al. 2014). Foliar spraying with IO_3^- and SeO_4^{2-} did not affect root uptake of iodine and selenium present in the nutrient medium. Foliar application of iodine together with selenium improved SeO_4^{2-} absorption by leaves when compared to plants sprayed only with Se.

9.5 Success Stories

9.5.1 Selenate Fertilization in Finland

The Se concentration of human diet can be increased by supplementing fertilizers with soluble Se compounds. In Finland, the availability of soil Se for plants is poor owing to the relatively low Se concentration, low pH and high iron content of the soil. Therefore, the Ministry of Agriculture and Forestry of Finland decided in 1984 to start supplementation of fertilizers with Se in order to enhance the Se intake of the Finnish population. The amount of Se added to fertilizers ranged from 6 to 16 mg kg^{-1}. Although Se is not an essential element for plants, they take up the mineral and complex it with organic compounds, which will be readily available to the population via plant and animal-based diet. Supplementation of fertilizers with Se as sodium selenate has been successful in increasing the Se intake of people in

Finland. The mean Se intake was increased by two to three-fold due to Se fertilizers used in crop production (Aro et al. 1995). A similar incident was also successfully implemented in New Zeland (Hartikainen 2005).

9.5.2 Zinc Fertilization in Turkey

Zinc deficiency is a serious nutritional problem for plants and humans in Turkey since around 14 Mha of cropped land in Turkey are Zn deficient. Between the years of 1993 and 1995, Zn fertilizer application was performed in field trials in order to enhance the Zn accumulation in cereal grains (Cakmak et al. 1999). Different fertilizer forms were applied from soil or foliage and the bioavailability of Zn nutrition was determined in different wheat and barley cultivars. According to the results of this study, Zn application resulted in 25% higher cereal yields with an increase in Zn content in edible parts of plants.

9.5.3 Iodine Fertilization in China

Severe iodine deficiency in Hotien prefecture, Xinjiang Province, China, potassium iodate supplementation was initiated in 1992 through irrigation water (Xin-Min et al. 1997). Potassium iodate was dripped into irrigation water during a 2- to 4-week period for 3 years, and iodine concentrations increased several folds in crops in urine of children 2–6 years of age. Higher iodine levels in the serum decreased the infant mortality rate by 50%.

9.6 Genetic Biofortification Strategies and Success Stories

In order to enhance the essential micronutrient levels in crop grains, crop breeding or transgenic approaches can be used.

9.6.1 Crop Biofortification via Conventional Breeding

Breeding is one of the most effective ways to produce the biofortified crops having high density of nutrients and vitamins. For this purpose, there must be a wide genetic diversity in the targeted crop regarding their nutritional value, and this value should be in the range that can influence human nutrition. In general, breeding for biofortification involves the screening of a gene pool for high nutritional value or mineral accumulation, and then crossing the determined parent lines with high mineral levels to the recipient high yielding, stress-tolerant cultivars over generations in order to get the new cultivars with desired nutritional and other agronomical characteristics. Finally, stability of mineral levels in the edible parts of the crop should be tested in target environmental conditions, and seeds should be distributed to the farmers.

Grain concentrations of minerals in maize, rice and wheat are quantitatively controlled and associated with low heritability (Gregorio 2002; Trethowan et al. 2005). In addition to these challenges, the large environment and genotype x environment interaction (GEI) effects slow progress in the genetic analysis of these traits (Ortiz-Monasterio et al. 2007).

9.6.2 Biofortification of Rice via Breeding

According to an estimate, rice feeds more than half of the world's population, thus biofortification of rice with essential micronutrients can reduce micronutrient deficiency in humans (Xuan 2018). Great emphasis has been paid for the biofortification of rice because of its lucrative effect to treat the malnutrition worldwide. After the screening of ancient rice varieties harboring high iron and zinc content, with the combination of improved mineral traits, biofortified rice was introduced through the breeding methods. Bangladesh Rice Research Institute is the pioneer institute for the development of zinc-enriched rice varieties that have been released (BRRI dhan 62, BRRI dhan 72, and BRRI dhan 64) in 2013 (Islam 2007; Behera et al. 2018; Valera et al. 2019). It is expected that their brown rice is potential enough to harbor 20–22 ppm of zinc in the grain. Another milestone was achieved by India and Philippines. They introduced a rice variety having 21 ppm of Zn in the grain through the cross between one improved line (IR68144-3B-2-2-3) and a variety with high yield (IR72) (Gregorio et al. 2000). As a further progress, a traditional variety named Jalmagna having double iron and 40% more zinc concentrations was chosen for breeding technique to develop a new rice variety with outstanding iron and zinc concentration (Gregorio et al. 2000).

Climate change is one of the major problems creating hindrance in zinc acquisition and assimilation in plants. Increasing carbon dioxide level in the atmosphere reduces the grain zinc content by disturbing its uptake and localization in plants (Nakandalage et al. 2016). In the year 2013, HarvestPlus had released the zinc-biofortified rice, which can be a potential source of zinc in the zinc deficient populations of the world (Bouis and Saltzman 2017).

9.6.3 Biofortification of Wheat via Breeding

Wheat is one of the major staple foods consumed by almost 35% of the world's population, which contributes about 20% of dietary energy and protein in most of the developing countries. Due to its extensive use in a number of products wheat is an ideal crop for the biofortification of mineral and vitamins (Singh et al. (2017a, b, c, d)). However, there is a major challenge in wheat breeding for improved micronutrient status. Farmers would only accept new biofortified varieties if there is a simultaneous enhancement of grain yield and micronutrient levels. However, the concentrations of micronutrients decrease when yield increases. Therefore, this challenge affects wheat-breeding strategies for biofortification.

Wheat has drawn first and foremost attention for bio-fortification because of its great diversity in iron and zinc enriched grain with existence of several wild species having evolutionary affinity has opened greater possibilities for the development of modern elite cultivars (Monasterio and Graham 2000; Cakmak et al. 2004; Ortiz-Monasterio al. 2007). In the year 2006, International Maize and Wheat Improvement Center (CIMMYT) initiated a wheat-breeding project in order to develop new wheat varieties biofortified with different essential minerals (Monasterio and Graham 2000). Hexaploid wheat was developed by crossing the tetraploid *Triticum durum* and high zinc-containing *Triticum dicoccum* with the *Aegilops squarrosa*, which is the D genome donor of the wheat. Primary hexaploid synthetic wheats with significantly higher Fe and Zn concentrations were used as non-recurrent parents in double backcrosses to adapted wheat at CIMMYT. Later, the plants were selected for disease resistance, high yield and high zinc and iron content (Guzmán et al. 2014; Singh et al. 2017a, b, c, d). Finally, the advanced lines with high levels of Fe and Zn were used in field trials in Mexico and South Asia. The effort of CIMMYT resulted in development of new lines in the wheat germplasm having high zinc and iron content. Until now, many zinc and iron-biofortified cultivars have been produced. Different varieties harboring 4–10 ppm improved zinc content was released by HarvestPlus utilizing this genetic variation in wheat. With correlation of this trend, another six wheat varieties having high zinc content were released by India in 2014, and Pakistan also inspired to release four varieties (NR 419, 42, 421, and Zincol) in 2015 (Garg et al. 2018). In 2017, Punjab Agricultural University and Indian Institute of Wheat and Barley Research introduced varieties containing high zinc (PBW1Zn) and iron (WB2), respectively. WB2 variety accumulates very high levels of zinc (42.0 ppm) and iron (40.0 ppm) in the grain (Yadava et al. 2018).

Using recombinant inbred lines (RILs) or doubled haploid (DH) populations, many quantitative trait loci (QTLs) related with grain micronutrient levels have been mapped in recent years (Buck et al. 2007; Distelfeld et al. 2007; Shi et al. 2008; Peleg et al. 2009; Tiwari et al. 2009; Devi et al. 2019). Advancements in genomics have been also integrated in wheat breeding for biofortification. For instance, a genome-wide association study (GWAS) of 123 synthetic hexaploid wheat (*Triticum durum* L. × *Aegilops tauschii* Coss.) lines identified 92 marker-trait associations (MTAs) of 10-grain minerals (Bhatta et al. 2018). Among them, 40 single nucleotide polymorphisms (SNPs) were located within genes. In a parallel GWAS, a population of 369 European elite wheat varieties were phenotyped for grain Fe content and several MTAs were determined (Alomari et al. 2019). Among these MTAs, a NAC transcription factor and several putative mineral transporters have been identified, suggesting new targets for wheat biofortification.

In 2005, IARI (Indian Agricultural Research Institute) has given priority to biofortification of pro-vitamin A in wheat and they were succeed to introduce durum wheat variety (HI 8627) containing high pro-vitamin A (Sharma et al. 2013). Last decades (before the 1970s), beside the new cultivars with beta-carotene, wheat having yellow pigment content (YPC; xanthophyll lutein) was released in different countries (Digesu et al. 2009; Ficco et al. 2014). With the contribution of anthocyanin, wheat varieties with elevated antioxidant properties have achieved another importance. Different countries have continued their breeding efforts with colored wheat (black, blue, and purple) and after the successive efforts for 20 years China was capable to release wheat with high protein and selenium content (Li et al. 2006). Further research on purple wheat cultivar was extended in several countries including Austria (Martinek et al. 2014) and Russia (Gordeeva et al. 2015).

9.6.4 Biofortification of Maize via Breeding

Having several utilities (animal feed, industrial purposes and human consumption) and a vast diversity in genetic makeup, maize has achieved much more breeding importance for high yielding varieties in recent centuries. Because of those favorable characteristics, researchers have utilized natural varieties with extended levels of pro-vitamin A to bread the high yielding biofortified maize having potentiality to combat vitamin A deficiency. At CIMMYT, carotenoid profiles of more than 1000 tropical genotypes have been screened to identify the genotypes with high pro-vitamin A levels (up to 8.8 μg/g) in the grain (Ortiz-Monasterio et al. 2012). In later studies, up to 20 μg/g (Babu et al. 2013) and 22.25 μg/g (Suwarno et al. 2014) pro-vitamin A levels have been identified (Fig. 9.2). Since 2013, biofortified orange maize has added new horizon in the agro-innovation of Zambia (GV662A, GV664A, and GV665A), Ghana (CSIR-CRI Honampa), Zimbabwe (ZS242), Tanzania and Nigeria (Ife maizehyb-4, Sammaz 38) (Pixley et al. 2013; CIMMYT 2016). Pro-vitamin A-biofortified maize hybrids (HP1097-18, HP1097-11 and HP1097-2) with high yields were successfully introduced in Pakistan (Maqbool 2017). Brazilian Agricultural Research Corporation (Embrapa) together with HarvestPlus developed maize synthetic cultivars with high levels of pro-vitamin A and carotenoids after two cycles of mass selection (Schaffert et al. 2011). Fifty F_1 single-cross yellow maize hybrids developed from Pakistan-originated parental lines were evaluated in field trials for yield, agronomic traits and pro-vitamin A content (Maqboool et al. 2017), and all of the traits were controlled by non-additive gene action, which indicates the manipulation of heterosis breeding for genetic improvement in maize. Recently, a potential research group from Zambia has demonstrated the positive role of biofortified maize with vitamin A for the improvement of pupillary response of children suffering from visual abnormalities (CIMMYT 2016). Besides the reservoir of antioxidant (tocochromanols, oryzanol) and phenolic compounds (Muzhingi et al. 2017), pro-vitamin A-biofortified maize has achieved another milestone as a potential source of quality protein (QPM). By the incorporation of *opaque-2* (*o2*) mutant gene isolated from wild type maize, scientist has developed QPM harboring elevated level of lysine and tryptophan (Palii and Batîru 2016; Krishna et al. 2017a, b; Pukalenthy et al. 2019). Maize enriched with quality protein has been released by CIMMYT in Mexico, India, China, Benin, Mozambique,

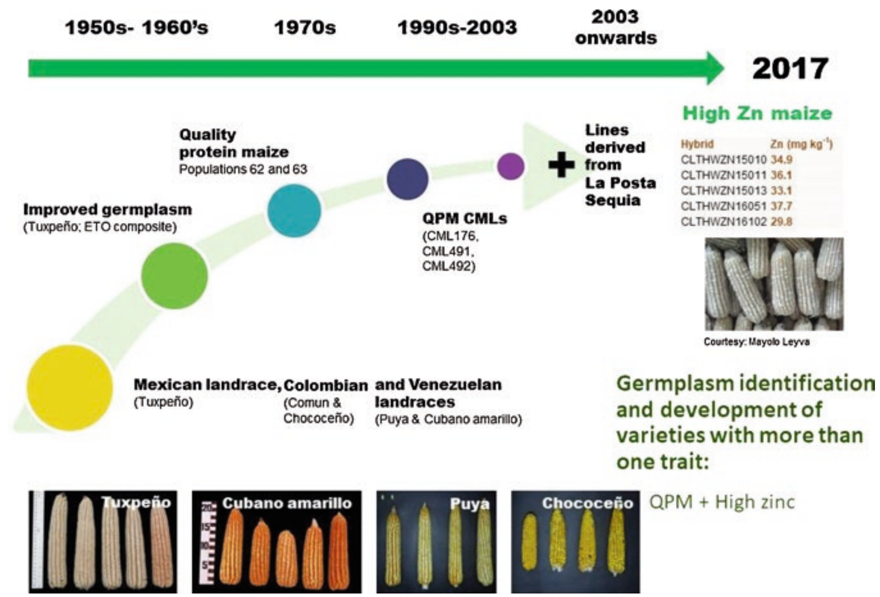

Fig. 9.2 The history of maize breeding program for biofortification at CIMMYT. (Source: CIMMYT Global Maize Program)

Venezuela, Brazil, South Africa, Ghana and Guatemala. Recently, marker-assisted selection (MAS) was deployed to pyramid the *opaque-2* (*o2*) and *β-carotene* (*crtRB1*) genes in maize that increased the lysine (0.294–0.332%), tryptophan (0.073–0.081%) and β-carotene (6.12–7.38 μg/g) content in maize grain (Chandran et al. 2019). Of late, recurrent selection scheme has been implemented to raise the carotenoids level (Palmer et al. 2016) along with vitamin E and phenolics (Goffman and Bohme 2001; Muzhingi et al. 2017).

Contrary to Vitamin A, iron and zinc biofortification of maize has been studied with limited success using *in vitro* and *in vivo* models for Fe bioavailability (Hoekenga et al. 2011). Nigerian study determined relatively small genotypic differences in grain Fe and Zn contents (Oikeh et al. 2003; Oikeh et al. 2004). Although a few varieties were recognized as encouraging, they were not pursued further. Screening of superior hybrids from CIMMYT represented that Fe bioavailability and Fe concentration were two distinct and unrelated traits; however, they were highly influenced by the environmental conditions (Pixley et al. 2011). A combined genetic, physiological and biochemical strategy was used to determine the QTLs related with higher Fe content in the grain and its bioavailability in a recombinant inbred (RI) population (Lung'aho et al. 2011). In this study, 3 QTLs were identified in relation to Fe bioavailability. In another study, genetically diverse inbred lines with high kernel Fe and Zn was used to develop Quality Protein Maize hybrids enriched with micronutrients together with lysine and tryptophan through microsatellite marker-based genetic screening (Pandey et al. 2015).

Marker-assisted introgression or backcrossing (Harjes et al. 2008; Yan et al. 2010; Muthusamy et al. 2014), Quantitative trait loci (QTL) and association mapping analysis (Islam 2004; Wong et al. 2004; Harjes et al. 2008), and GWAS (Lu et al. 2011; Romay et al. 2013; Suwarno et al. 2015) was utilized extensively in development of biofortified maize varieties.

9.6.5 Biofortification of Sorghum via Breeding

To enhance the minerals, beta-carotene and protein (Waters and Pedersen 2009), lutein and zeaxanthin contents (Fernandez et al. 2009), sorghum has been biofortified and sorghum germplasm denotes great variability with genetic heritability for iron and zinc content (Kumar et al. 2013). More than two thousands and two hundreds of germplasm accessions were screened and promising ones were identified with high levels of Fe and Zn under HarvestPlus for development of new sorghum parental inbred lines and hybrids with high Fe and Zn content at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). They also released iron-enriched sorghum lines (ICSH 14002, ICSR 14001) with few hybrids in India (Neeraja et al. 2017). New sorghum varieties (12KNICSV-188 and 12KNICSV-22) with increased amount of Fe in Nigeria positively regulated Fe status among the children suffering from malnutrition and sorghum variety 12KNICSV-188 contained three times higher iron level.

9.6.6 Biofortification of Millets via Breeding

Pearl millet regard as an abundant source of zinc and iron (Rao et al. 2006) having remarkable variation in genetic makeup of these micronutrients (Velu et al. 2007). HarvestPlus 2014 of ICRISAT in India has released biofortified pearl millet (Dhanashakti) variety with one hybrid (ICMH 1201 - Shakti-1201) and currently two varieties, ICMH 1301and ICMH 1202 (Nirmal-7) are under field trial. Besides that, several commercial varieties with acclimatization, more than one progenies and hybrids with elevated amount of zinc and iron in millets have been reported (Velu et al. 2007; Rai et al. 2012).

9.6.7 Biofortification of Legumes via Breeding

High heritability was observed in iron, zinc and protein content in pulses. Partnership between ICARDA's Biodiversity and Integrated Gene Management Program and HarvestPlus led the screening of Fe, Zn and protein levels in more than 1700 germplasms including wild species, breeding lines, and released cultivars from around 20 countries (Sen Gupta et al. 2016). There was a wide range of Fe and Zn contents in the lentil seeds. Therefore, breeding efforts started in 2006, at the end of which several High iron and zinc lentil varieties have been released, including five in Bangladesh (Barimasur-4, Barimasur-5, Barimasur-6, Barimasur-7, and Barimasur-8), seven in Nepal (ILL 7723, Khajurah-1, Khajurah-2, Shital, Sisir Shekhar, Simal), two in India (L4704, Pusa Vaibhav), one in Ethiopia (Alemaya), and two in Syria (Idlib-2, Idlib-3) (Sarker and Agrawal 2015). Microsatellite (Singh et al. 2017a, b, c, d) and SSR marker-based screening (Mehra et al. 2018) together with association mapping (Singh et al. 2017a, b, c, d) were also used in development of high Fe and Zn containing lentil germplasm. Lentil genotypes were screened for variation in phytate (Thavarajah et al. 2009) and Se content (Thavarajah et al. 2008) in order to develop lentil cultivars with low phytate and high selenium levels in the seeds, respectively (Thavarajah et al. 2011). QTLs related with high Se content in the seeds have also been determined in a 96-lentil RIL population (Ates et al. 2016).

Cowpea has been iron-enriched under HarvestPlus framework. Pant Lobia-1 (2008), Pant Lobia-2 (2010), Pant Lobia-3 (2013), and Pant Lobia-4 (2014) varieties with enhanced iron content have been released in India (da Silva et al. 2018). Similar breeding strategies have been achieved in Brazil to develop new varieties with high seed protein and mineral composition (Santos and Boiteux 2013).

At HarvestPlus, target iron level for common beans was 94 μg/g, which represented an increase of 44 μg/g as compared to the average concentration in the germplasm. Target has been achieved (Blair et al. 2010; Ribeiro et al. 2013), and the human studies challenging the performance of biofortified beans demonstrated their efficient use in human diet (Petry et al. 2012). Common bean varieties with high levels of Fe have been released in Rwanda (RWR 2245, RWR 2154, MAC 42, MAC 44, CAB 2, RWV 1129, RWV 3006, RWV 3316, RWV 3317, and RWV 2887) and the Democratic Republic of Congo (COD MLB 001, COD MLB 032, HM 21-7, RWR 2245, PVA 1438, COD MLV 059, VCB 81013, Nain de Kyondo, Cuarentino, Namulenga) (Petry et al. 2015). Several QTL analyses have been conducted in common bean and Andean bean to identify regions associated with high seed Fe and Zn contents (Guzman-Maldonado et al. 2003; Cichy et al. 2009; Blair et al. 2010; Blair et al. 2011, 2013; Blair and Izquierdo 2012; Izquierdo et al. 2018).

Various researchers have reporter a wide range of variation in seed Fe and Zn contents (Thavarajah 2012; Tan et al. 2018; Vandemark et al. 2018) as well as carotenoid amount (Ashokkumar et al. 2015) in chickpea. QTLs related with seed Fe and Zn contents have been identified in chickpea (Diapari et al. 2014; Upadhyaya et al. 2016). Recently, SNPs linked with seed copper, phosphorus, and potassium levels (Ozkuru et al. 2018) and seed molybdenum and selenium levels (Ozkuru et al. 2019) were determined in chickpea.

9.6.8 *Biofortification of Potato via Breeding*

Micronutrient analyses of potato have focused primarily on Fe and Zn. Fe content of potato varieties reportedly showed a wide range with concentrations among the landraces of South America two to three times greater than in the cultivated varieties in the U.S. and Europe (True et al. 1978; Warman and Havard 1998; Rivero et al. (2003a,b); Andre et al. 2007; Burgos et al. 2007; Brown et al. 2010; Haynes et al. 2012). A large genepool was screened for tuber Fe and Zn contents by International potato center (CIP). CIP and HarvestPlus have developed high iron and zinc advanced breeding material after crossing diploid Andean landrace potatoes with high zinc and iron with disease resistant tetraploid clones. The new biofortified potatoes have tubers with 60–80% higher zinc and iron content than local cultivars (Andersson et al. 2017). Biofortified potatoes were taken into adaptation studies in two target countries Rwanda and Ethiopia. These advanced lines accumulated up to 60% higher zinc and iron content in their tubers than local cultivars, and they were applied for official release in Rwanda in 2017.

9.6.9 *Biofortification of Cassava via Breeding*

As a staple food for countries in Africa, Latin America, and the Caribbean, HarvestPlus targeted cassava for enhancement of pro-vitamin A (beta-carotene) levels. After extensive breeding efforts, six varieties with high levels of Vitamin A have been released in Nigeria (2011; TMS 01/1368—UMUCASS 36, TMS 01/1412—UMUCASS 37 and 2014; TMS 01/1371—UMUCASS 38 and NR 07/0220—UMUCASS 44, TMS 07/0593—UMUCASS 45, and TMS 07/539—UMUCASS 46) and one in the Democratic Republic of Congo [Kindisa (TMS 2001/1661)]. Moreover, similar studies have been performed to enhance the Fe and Zn levels in cassava roots since a high genetic variation in total carotene, iron, and zinc contents of cassava genotypes have been reported (Maziya-Dixon et al. 2000).

9.7 Success Stories

9.7.1 *Orange Sweet Potato*

Orange flesh sweet potato varieties with high levels of vitamin A and carotenoids developed by HarvestPlus and CIP have been released in several African countries including Uganda, Mozambique, Kenya, South Africa and Nigeria (Neela and Fanta 2019). Six varieties have been released in Uganda (Ejumula, Kakamega, Vita, Kabode, Naspot 12O, and Naspot 13O) and three in Zambia (Twatasha, Kokota, and Chiwoko). CIP reported that sweet potato is third vital food crop in seven central and eastern African countries, fourth priority crop in six South African nations, and eighth in four West African countries (International Potato Center 2017). Together with relevant nutrition education, addressing household food and nutrition security, production and consumption of orange sweet potato has been increased in African countries, and now it became a staple food. For these efforts, they have been awarded the World Food Prize-2016. Biofortified orange sweet potato varieties have been released in many parts of Asia (China, Bangladesh, and India) and Latin America.

9.7.2 Iron Beans

Iron-biofortified beans were designed to combat iron deficiency in African population by HarvestPlus. The first country selected for release of Fe-enriched bean varieties was Rwanda, where 10 varieties were released between 2010 and 2012 after adaptation studies. They came in different colors, sizes, and other characteristics to appeal to bean producers and consumers. The varieties have approximately twice as much iron content as local varieties. Consumption of iron-enriched beans improved blood iron levels after only a few months (Haas 2014; Haas et al. 2016; Finkelstein et al. 2017). Women with iron deficiency anemia experienced improved cognitive skills and physical activity after consumption of iron-enriched beans (Luna et al. 2015; Murray-Kolb et al. 2017). Since 2012, HarvestPlus and its partners have distributed Fe-enriched beans to small landholders in Rwanda through formal delivery approaches, and as a result, approximately 28% of rural households in the country grew an Fe-enriched bean variety between 2012 and 2015 (Vaiknoras and Larochelle 2018).

9.8 Crop Biofortification via Genetic Engineering

In case of transgenics, enrichment of essential micronutrients in crop grains can be done by incorporation of genes involved in mineral uptake, translocation, distribution and sequestration. Originated from different organisms, such as bacteria, archaea or other plants, or the host plant itself, the genes involved in nutrient bioavailability, inhibition of nutrient-limiting factors, deposition of micronutrients in edible plant organs, re-engineering of biological pathways can also be done easily via genetic engineering and genome editing. Various crop species have been genetically engineered to enrich micronutrient, vitamin, essential amino acid and fatty acid levels in edible parts by overexpression or suppression of at least one gene involved in mineral metabolism, and they are discussed in this section.

9.8.1 Biofortification of Rice by Transgenic Approaches

To address the global concern of malnutrition, rice has drawn the attention of scientific community. Prevalence of night blindness due to lack of vitamin A is a remarkable challenge in underprivileged population of least developed countries. Introduction of golden rice by the expression of carotene desaturase and *PSY* is the abundant source of beta-carotene (pro-vitamin A) providing a new dimension with a significant potentiality to treat the unpleasant night blindness (Burkhardt et al. 1997; Ye et al. 2000; Beyer et al. 2002; Datta et al. 2003; Paine and Shipton 2005). By targeting the gene responsible for carotene desaturase, precursor of beta-carotene (phytoene) level has been uplifted more than 23 folds (Burkhardt et al. 1997). Up to date, vitamin B9 (folic acid) has outstanding role to mitigate the anemia during pregnancy. To initiate rice with increased level of folic acid, transgenic rice has been developed by the overexpression of *GTPCHII* (*Arabidopsis* GTP-cyclohydrolase I GTPCHI) and *ADCS* (aminodeoxychorismate synthase) genes that ensured elevated level of folate (more than 150 folds). This GMO rice was proven to be potential enough to fulfill the daily requirement of folate for the adult individuals (Storozhenko et al. 2007; Blancquaert et al. 2015).

In order to mitigate the global challenge of iron deficiency anemia, several efforts were launched to develop iron-enriched rice varieties by the expression of genes encoding for an iron transporter *OsIRT1* (Lee et al. 2009), a nicotianamine aminotransferase (Takahashi et al. 2001), a common bean ferritin *FER* (Lucca et al. 2002), a soybean ferritin *FER* (Goto et al. 1999; Vasconcelos et al. 2003; Trijatmiko et al. 2016) and nicotianamine synthase genes (*OsNAS1* and *OsNAS2*) (Lee et al. 2009, 2012; Trijatmiko et al. 2016). Beside this, another milestone was achieved to develop the iron bioavailability in rice by reducing anti-nutrient compound phytic acid (Hurrell and Egli 2010). Rice genome was also modified to release the rice variety enriched with zinc by the overexpression of genes responsible for mugineic acid synthesis (*HvNAS1, HvNAAT-A, IDS3HvNAS1, HvNAAT-B and HvNAS1*) from barley (Masuda et al. 2008). However, the most effective transgenic technology used in rice was simultaneous overexpression of multiple genes involved in Fe uptake, translocation and sequestration in the grain (Wirth et al. 2009; Masuda et al. 2012, 2013).

Similar to the development of Fe-biofortified rice varieties, overexpression of genes involved in Zn uptake, translocation and sequestration helped the development of new varieties with improved bioavailability of Zn without yield penalty in an essential way to increase the grain Zn content (Borrill et al. 2014). Overexpression of *OsNAS1* under the control of a constitutive promoter (Lee et al. 2009) or barley *HvNAS1* under the control of the rice actin1 (Masuda et al. 2009) caused up to threefold of increase in grain Zn levels. International Rice Research Institute (IRRI) developed thousands of transformants of IR64 and IR69428 containing soybean or rice ferritin and *OsNAS2* overexpression, and the grain contents of Zn and Fe in those lines have exceeded the expected levels in field trials (Zheng et al. 2010). Overexpression of phytase gene (*phyA*) from *Aspergillus* species has been used to breakdown antinutrient phytate in rice grains to enhance the nutritional value (Lucca et al. 2001; Gontia et al. 2012). RNAi-mediated seed-specific silencing (using the Oleosin18 promoter) of the *IPK1* gene involved in phytic acid biosynthesis in rice demonstrated higher bioavailability of Fe and Zn in the grains (Ali et al. 2013).

Elevated protein quality in rice also ensured by the targeting of essential amino acid through the incorporation of seed-specific genes of Sesame 2S Albumin (Lee et al. 2003), bean β-phaseolin (Zheng et al. 1995), pea legumin (Sindhu et al. 1997), dihydrodipicolinate synthase (DHPS) (Yang et al. 2016), soybean glycinin (Katsube et al. 1999) and *E. coli* aspartate aminotransferase (Zhou et al. 2009). For the improvement of human health status and reduction of bad cholesterol levels, transgenic rice was also introduced with good quality seed oil by increasing the level of polyunsaturated fatty acid and α-linolenic acid that uplifted by the expression of *GmFAD3* gene (omega-3 fatty acid desaturase) (Anai et al. 2003). By the expression of Maize C1 with regulatory genes of R-S (Myb-type transcription factors) (Shin et al. 2006) and *CHS* (chalcone synthase) genes (Ogo et al. 2013), a new rice variety was introduced that was enriched with flavonoids. Presently, over-nutrition and obesity also regarded as a big threat to the sound health. A rice variety was developed harboring resistant and less digestible amylose starch by the expression of antisense waxy genes (Itoh et al. 2003; Liu et al. 2003) and antisense RNA inhibition of SBE (starch-branching enzymes). Of late, incorporation of lactoferrin (functional protein found in human milk) into rice has opened a new window of possibility to create a value-added cereal-based ingredient into infant food formula (Nandi et al. 2002; Lee et al. 2010).

9.8.2 Biofortification of Wheat by Transgenic Approaches

Biofortified wheat has been proven an efficient source to alleviate the crucial nutritional deficiencies of quality proteins, vitamin A and iron. Wheat with the expression of bacterial *PSY* with carotene desaturase genes (*CrtB, CrtI*) has denoted uplifted beta-carotene content (Cong et al. 2009; Wang et al. 2014). Integration of ferritin gene in wheat isolated from soybean revealed elevated amount of iron content in wheat (Borg et al. 2012; Xiaoyan et al. 2012). Expression of a phytochrome gene (*phyA*) improved the phytase activity in wheat that ensured increased iron bioavailability (Brinch-Pederson et al. 2000) whereas the silencing of a wheat transporter (*ABCC13*) decreased phytic acid content (Bhati et al. 2016). Protein (lysine, methionine, cysteine, and tyrosine amino acids) content was enhanced by the utilization of *ama1* gene (Amaranthus albumin) (Tamas et al. 2009). Maize regulatory genes (C1, B-peru, contribute to the production process of anthocyanin) were incorporated in wheat, and the transgenic wheat showed increased antioxidant activity (Doshi et al. 2006). Silencing of *SBEIIa* gene (gene encoding SBE) was used to develop a new variety of wheat having less digestible and resistant amylose starch that was potential to solve the health disorders regarding over-nutrition and obesity (Sestili et al. 2010).

Previous Fe and Zn biofortification strategies in wheat include the overexpression of soybean ferritin or wheat *NAS2* alone or together, which increased iron levels up to 2.2 folds (Singh et al. 2017a, b, c, d). Recently, overexpression of wheat vacuolar iron transporter *TaVIT2* under the control of an endosperm-specific promoter, more than 2-folds of iron was accumulated in white flour fractions without effecting the level of phytate (Connorton et al. 2017). Overexpression of *Aspergillus phyA* under a constitutive (Ubi) promoter in wheat demonstrated slight decrease in phytate levels in the seeds (Brinch-Pedersen et al. 2000, 2003). Recently, wheat transgenic plants expressing *Aspergillus japonicus phytase* gene (*phyA*) in wheat endosperm exhibited 12–76% reduction of phytate content in seeds depending on the copy number, and their seeds accumulated significantly higher levels of bioavailable Fe and Zn (Abid et al. 2017). Similar to the transgenic rice, transgenic hexaploid wheat lines were developed by RNAi-mediated gene silencing of *IPK1* gene, and the lines demonstrated 28–56% reduction in phytic acid levels while a significant increase in Fe and Zn contents were achieved in the seeds (Aggarwal et al. 2018).

9.8.3 Biofortification of Maize by Transgenic Approaches

To date, through the manipulation of genetic constitute, maize has been considered as a potent source of vitamins, minerals, quality protein and anti-nutrient. Expression of different carotenogenic genes (Zhu et al. 2008; Khush et al. 2012; Decourcelle et al. 2015) and bacterial *crtB* produced transgenic maize enriched with carotenoids (pro-vitamin A). By the over expression of *HGGT* (homogentisic acid geranylgeranyl transferase), maize verity enriched with tocotrienol and tocopherol was developed and it was capable to substitute vitamin E along with its analog, and is regarded as a potent source of antioxidants (Cahoon et al. 2003). Transgenic maize developed by the expression of *DHAR* (dehydroascorbate reductase) improved vitamin C (L-ascorbic acid) about 100-folds (Chen et al. 2003) that was useful for cardiovascular abnormalities and immune cell development. Beside these, Naqvi et al. (2009) manipulated three remarkable metabolic pathways and developed multivitamin maize accumulating two-fold, six-fold and 169-fold elevated folate, ascorbate and beta-carotene, respectively. Incorporation and expression of soybean ferritin (Drakakaki et al. 2005), *Aspergillus* phytase (Aluru et al. 2011) and *Aspergillus niger phyA2* (Chen et al. 2008) and silencing the expression of multidrug resistance-associated protein (Shi et al. 2007) reveals increased iron bioavailability in maize. Significant milestone has been achieved in cases of essential amino acid content in maize and it was achieved by the expression of *sb401* gene from potato (Tang et al. 2013; Yu et al. 2005). Lysine and tryptophan-enriched maize was introduced by the antisense dsRNA targeting alpha-zeins (Huang et al. 2006) and recently world's largest agri-biotech company Monsanto has developed a lysine-enriched maize variety in Japan and Mexico. Later, this innovation (Maize LY038) was adopted by different countries. Modification of *cis*-acting site for *Dzs10* (Lai and Messing 2002) and overexpression of milk protein α-lactalbumin (Yang et al. 2002) has enabled the scientific community to release maize varieties with increased amount of methionine and others amino acid balance, respectively.

9.8.4 Biofortification of Barley by Transgenic Approaches

Barley harboring elevated levels of micronutrients, especially iron and zinc was developed by the overexpression of zinc transporters (Ramesh et al. 2004) and expression of phytase gene (*HvPAPhy*_a) (Holme et al. 2012). Engineering of DHPS gene (*dapA*) into barley showed increased amount of lysine (Ohnoutkova et al. 2012). The amount of important dietary fibers β glucans were increased by the elevated expression of *HvCslF* (gene responsible for cellulose synthesis) (Burton et al. 2011) and this transgenic barley was proven to be useful to treat serious human diseases including cardiovascular disease and type II diabetes (Dikeman and Fahey 2006). Barley with γ-linolenic acid, polyunsaturated fatty acids and stearidonic acid (STA) that promote health status was developed by the expression of Δ6-desaturase (D6D) (Mihalik et al. 2014). Transgenic barley also produced through the expression of genes responsible for human lactoferrin (HLF) (Kamenarova et al. 2007). Beside these, important bioactives (antibiotics and enzymes) having medical and industrial uses have also been produced in transgenic barley.

9.8.5 Biofortification of Sorghum by Transgenic Approaches

Sorghum having elevated level of beta-carotene (pro-vitamin A) expressing *Homo188-A* is the remarkable achievement of the time (Lipkie et al. 2013). Of late, by the incorporation of HT_{12} (high lysine protein), transgenic sorghum was developed that revealed enriched content of essential amino acid especially lysine (Zhao et al. 2003) compared with another major staple crop. Transgenic sorghum with suppression of three important genes (*γ-kafirin-1, γ-kafirin-2* and α-*kafirinA1*) (Grootboom et al. 2014) and RNAi mediated silencing of the *γ-kafirin* (Elkonin et al. 2016) ensured increased digestibility index of sorghum.

9.8.6 Biofortification of Cassava by Transgenic Approaches

The BioCassava Plus program has employed modern biotechnologies intended to improve the health of Africans through the development and delivery of genetically engineered cassava with increased nutrient (zinc, iron, protein, and vitamin A) levels (Sayre et al. 2011). Overexpression of the vacuole membrane localized ZAT gene was used to increase the tuberous root zinc content fourfold under the control of patatin promoter from *Solanum tuberosum* (potato) (Siritunga and Sayre 2003). Overexpression of an *Arabidopsis* ZIP plasma membrane zinc transporter enhance the root Zn levels up to two folds (not published). Overexpression of Chlamydomonas reinhardtii iron-specific assimilatory protein (*FEA1*) under the control of patatin promoter enhanced the Fe accumulation in the roots (Ihemere et al. 2012). Overexpression of *VIT1* from Arabidopsis controlled by a patatin promoter enhanced the iron content of cassava tubers 3- to four-fold (Narayanan et al. 2015). Simultaneous overexpression of *crtB* phytoene Synthase gene from *Erwinia herbicolor* and 1-deoxy-d-xylulose-5-phosphate synthase gene (*DXS*) from *Arabidopsis thaliana* under the control of patatin promoter significantly enhanced the beta-carotene levels in transgenic cassava roots (Telengech et al. 2015). Overexpression of phytoene synthase (*PSY*) genes enhanced Vitamin A content in cassava (Welsch et al. 2010).

9.8.7 Biofortification of Potato and Sweet Potato by Transgenic Approaches

Similar to other crops, pro-vitamin A content of potato tubers was enhanced by overexpression of phytoene synthase *PSY* gene *(crtB)* from *Erwinia uredovora* (Ducreux et al. 2004) and by co-expression of *PSY, phytoene desaturase*, and *lycopene β-cyclase* genes (Diretto et al. 2006). Overexpression of lycopene β-cyclase (*StLCYb*) enriched the β-carotene content in tubers (Van Eck et al. 2007). β-carotene in tubers was also enhanced by using RNAi to silence the β-carotene hydroxylase gene (*bch*) that functions in production of zeaxanthin from β-carotene (Song et al. 2016). Suppression of zeaxanthin epoxidase gene was also used in development of a zeaxanthin-rich potato line (Römer et al. 2002). Overexpression of truncated form of vacuolar Ca^{2+} transporter *CAX2B* from *Arabidopsis thaliana* enhances the calcium accumulation up to 65% more in potato tubers (Kim et al. 2006).

Overexpression of strawberry *GalUR* enriched the tubers with vitamin C (Upadhyaya et al. 2009), overexpression of cystathionine γ-synthase (*CgSΔ90*) and methionine-rich storage protein (15-kD β-zein) genes enriched the tubers with methionine (Dancs et al. 2008). Methionine content in tubers was also enhanced by RNAi-based silencing of *StMGL1* (Huang et al. 2014) and knockdown of threonine synthase genes (Zeh et al. 2001). Overexpression of *Klebsiella pneumonia* cyclodextrin glycosyltransferase gene in potato enhanced the conversion of starch into cyclodextrin, a novel carbohydrate (Oakes et al. 1991). Simultaneous overexpression of genes encoding for chalcone synthase (CHS), chalcone isomerase (CHI), and dihydroflavonol reductase (DFR) resulted in a significant increase of phenolics and anthocyanins in transgenic potato tubers (Lukaszewicz et al. 2004). Transgenic potato varieties engineered for reduced amylose and increased amylopectin concentrations, and limited formation of reducing sugars have been registered by different companies in Europe, the USA, Canada and Japan.

RNAi-based silencing of the lycopene ε-cyclase gene increases carotenoid synthesis in sweet potato converting the white flesh into yellow (Kim et al. 2013). Overexpression of the *IbMYB1* gene in an orange-fleshed sweet potato cultivar under the control of either the storage root-specific sporamin 1 (*SPO1*) promoter or the oxidative stress-inducible peroxidase anionic 2 (*SWPA2*) promoter produces a dual-pigmented transgenic sweet potato with improved phenolic content and antioxidant activity (Park et al. 2015).

9.8.8 Biofortification of Soybean by Transgenic Approaches

Similar to other crops, overexpression of a phytoene synthase gene (*crtB*) from *Pantoea ananatis* enhanced the accumulation of β-carotene in plastids together with oleic acid and seed protein (Schmidt et al. 2015). Overexpression of *crtB* gene simultaneously with ketolase genes (*crtW* from *Brevundimonas* sp. strain SD212 and *bkt1* from *Haematococcus pluvialis*) under the control of seed-specific promoters enhanced the accumulation of ketocarotenoids and other compounds in the carotenoid pathway in soybean seeds (Pierce et al. 2015). Transgenic soybean lines expressing Phytoene synthase-2A-Carotene desaturase gene under the control of the β-conglycinin or CaMV-35S promoters enhanced the levels of β-carotene and total carotenoids in the seeds (Kim et al. (2012a, b)). Transgenic plants expressing Arabidopsis cystathionine γ-synthase gene (*AtCGS1*) under the control of a seed-specific promoter, legumin B4 (Song et al. 2013), or the mutated form of *AtCGS1* that shows a better function under the control of a seed-specific glycinin gene promoter (Hanafy et al. 2013) accumulated at least two-fold higher soluble methionine levels than non-transgenics. By overexpression of a 15 kDa zein protein gene (Dinkins et al. 2001) or cytosolic isoform of O-acetylserine sulfhydrylase (Kim et al. (2012a, b)), researchers were able to increase the seed methionine and cysteine contents up to 74%.

Overexpression of the gene encoding for 2-methyl-6-phytylbenzoquinol methyltransferase in soybean specifically in the seed caused an eight-fold increase of α-tocopherol and an up to five-fold increase in seed vitamin E (Van Eenennaam et al. 2003). A chimeric gene (CRC) containing a fusion of maize nucleotide sequences encoding C1 and the Lc allele of R under control of the seed-specific phaseolin promoter increased the accumulation of isoflavones in the seeds (Yu et al. 2003).

RNAi-based silencing of endogenous Δ-12 oleate desaturase *GmFad2-1b* in soybean lead to a significant increase in oleic acid and a reduction in palmitic acid in their seed oil content (Zhang et al. 2014). Overexpression of *Borago officinalis* Δ^6-desaturase gene under the control of embryo-specific promoter β-conglycinin enhanced the accumulation of α-linolenic acid and stearidonic acid in seeds (Sato et al. 2004). Co-expression of the *Borago officinalis* Δ^6 desaturase and the Arabidopsis Δ^{15} desaturase under the control of seed-specific promoter resulted in high accumulation of stearidonic acid in the seeds of transgenic soybean (Eckert et al. 2006). siRNA-mediated gene silencing of the omega-3 fatty acid desaturase (*FAD3*) gene in soybean leads to low α-linolenic acids (18:3) (Flores et al. 2008). Private companies have released transgenic soybean varieties rich in oleic and linoleic acids in various countries.

9.8.9 Biofortification of Vegetables by Transgenic Approaches

Overexpression of Arabidopsis H^+/Ca^{2+} transporter *CAX1* in carrots enhanced Ca^{2+} levels up to 2 folds, and when crossed with a commercial carrot variety, *CAX1*-overexpression phenotype could be transferred to the variety (Park et al. 2004). Interestingly, the serum level of Ca^{2+} in human subjects was increased when they were fed with transgenic carrots (Morris et al. 2008). A similar technique was applied to tomatoes in order to increase the calcium levels as well as the shelf life (Park et al. 2005). Overexpression of soybean ferritin in lettuce enhanced Fe levels up to 1.7 times while significantly increasing the biomass (Goto et al. 2000).

9.9 Conclusion

Deficiency of micronutrients including selenium, zinc and iron is a major concern especially in South Asia, Africa and Latin America where majority of population have a limited access to a variety of food products in order to fulfil their nutrient requirements. To cope with the issue of mineral deficiency, many efforts are being made for the genetic improvement of crops. These efforts focus on increasing the bioavailable nutrient contents of the staple grains, seeds or other edible parts either through conventional breeding, or genetic engineering, or agronomic practices. Among three strategies of biofortification, crop-breeding integrating the molecular techniques can be the most successful solution in a long term using crop varieties with increased nutrient bioavailability. However, as the donor parental lines have been used in previous breeding efforts and the gene pool for biofortification demonstrate limited variability, it will be more difficult and time-consuming to develop new varieties with nutrients levels more than the released varieties by using present breeding techniques. Therefore, it is more feasible to get the benefit from transgenic technologies to develop new varieties biofortified beyond present achieved levels. However, transgenics have their own limitations, especially in public acceptance, gene flow and other agronomical features that is the most critical consideration in any breeding programs. Luckily, recent developments in genome editing may eliminate some of these limitations; therefore, we may see the development and release of new crop varieties biofortified with various nutrients simultaneously in near future.

The conventional breeding and genetic engineering have been used extensively in development of crop species tolerant to environmental stress conditions, where the priority of a breeding program was always given to the high yield performance. As the climate change is expected to cause more severe environmental stresses on crops, their yield is expected to drop significantly in next century. Therefore, breeding programs are more and more concentrated on developing varieties giving higher yields in adverse climate change scenario. Although this would suggest that breeding programs concerning about biofortification are less important than the ones on environmental stress tolerance, the success stories of biofortification studies are undeniable.

In 2004, the HarvestPlus was launched for biofortification research on beans, cassava, maize, pearl millet, rice, sweet potato, and wheat for iron, zinc and vitamin A. The program became a big success in 15 years by releasing more than 150 biofortified varieties across 10 crops in 30 countries, many of which are developing countries with extensive malnutrition and hidden hunger problems (Bouis and Saltzman 2017). The program distributed the biofortified seeds to the farmers, educated the villagers and implemented governmental changes in regulation and support of biofortified crop production in those countries. Therefore, the success of the program went beyond its lifetime.

Fertilization usage at proper doses and developmental stages has been shown to be critical for agronomic biofortification. This strategy was successfully implemented in tens of countries, either developed or developing, with outstanding results. However, the success of agronomical biofortification is highly variable due to environmental conditions. It was reported that the nutrient bioavailability in rhizosphere and plant uptake is highly affected by environmental stresses such as drought and high temperature. Therefore, it will not be difficult to speculate that the success of agronomic biofortification would decrease dramatically with climate change in near future, suggesting that the farmers would be forced to use more fertilizers in order to achieve the present day nutrient levels in crops. Of course, extensive usage of fertilizers is dangerous for the environment and human health in turn. Hence, governments should come up with new regulatory mechanisms to control the widespread fertilizer usage in near future. Moreover, there are several reports proving the use of macro- and/or micronutrients in alleviation of negative effects of environmental stresses on crops. Therefore, agronomic biofortification under climate change will be an interesting new frontier for breeders, agronomists and plant scientists in next century.

Breeding programs concerned with the development of new varieties biofortified with nutrients take advantage of high yielding and/or environmental stress-tolerant parents at the beginning of the process. Then, the developed varieties carry the characters of biofortification, high yield and tolerance to some stresses. They need to pass through adaptation studies in different countries under different environmental conditions. Hence, biofortification breeding programs are not different from normal breeding programs. In addition, people at high risk of hidden hunger and malnutrition in developing countries always ask for better quality of food in cheaper prices. Therefore, development of new varieties tolerant to climate change, giving high yields and enriched with nutrients are needed in future world. Then, poor people can grow these varieties successfully by fertilizer applications to increase the nutrient levels while protecting them against adverse effects of climate change.

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Chapter 10
QTL Mapping for Abiotic Stresses in Cereals

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Abstract Mapping of quantitative trait loci (QTL) brought a revolutionary breakthrough in the world of crop production. Salinity, drought, water logging and toxicity are those abiotic stresses that affect the crop yield and production. Tolerance for stress is a difficult operation that the plant needs to undergo in order to survive. QTL identification and mapping has made it easy for the plant breeders to better understand the abiotic stress-tolerance mechanisms, leading to increase the crop productivity and yield. In this chapter, we have discussed the stresses, their impact on crops and portrayed distinctive abiotic stress tolerant related QTLs that have been pointed out in important cereal crops like rice, wheat and maize. We have summarized certain approaches which would be more helpful for mapping the genomic regions that were responsible for stress tolerance. The developing view of this chapter will highlight the importance of QTL mapping to produce abiotic stress-resistance crops in future.

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_10

Keywords QTL · Stress tolerance · Crop productivity and yield

10.1 Introduction

The nature affects everything either it is living or non-living. As the human populace is rising continuously, the demand of food is also rising exponentially. By 2050, the agriculture sector needs to feed a population of over 9 billion people. Energy requirements of most of the people today are met by consuming cereals. Sadly, cereals production including foremost significant crops like maize, wheat and rice are extremely targeted by abiotic stresses including Drought, Water logging, Salinity, Frosting and Heavy metal abundance (Begcy and Dresselhaus 2018; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017). These abiotic stresses affect the plant's growth and productivity by interfering in their structural, functional, biochemical and molecular systems and hindering their proper functioning (Jaleel et al. 2009). Intrinsically, plants use compounds and elements like water, light, carbon and mineral nutrients for their nourishment. Abiotic stresses can be described as the environmental factors that minimize growth and production of yield (Cramer 2010; Skirycz and Inze 2010). Plant breeders identify several functional and regulatory genes which are up- or down-regulated in response to abiotic stresses. Generally, plants response varies to abiotic stresses, relying upon plant species, genotypes, age, plant organ, stress intensity and temporal order of stress application (Ahmad et al. 2018). This chapter describes the impact of abiotic stresses on the nature of cereals and explains how quantitative traits loci (QTLs) help researchers to improve cereals to withstand against these stresses. Since the genetic premise of stress tolerance to abiotic stress is basically quantitative. In this chapter, we demonstrate and talk about numerous studies of QTLs reported in cereals, that are significant in imparting tolerance to adverse environmental conditions (Tuberosa and Salvi 2004). QTL mapping acts as a mean to identify characteristic areas on chromosomes, the immensity of phenotypic expressions, number, and mode of gene activity of determinants that are responsible and influence the inheritance of continuously variable traits. This mapping technique works on the principle of extracting the genetic signals from one particular locus by use of noise produced in response to microclimatic variations. The QTL mapping is a well-implemented field not only in life sciences but agriculture as well. The specific biochemical process of plants and their affiliation to external conditions such as drought, stress resistance and disease resistance are considered to be the complex endpoint measurements due to lack of approaches to determine them. However, the QTL mapping can be readily applied to determine such complex end-point estimations within the non-appearance of biochemical information (Paterson 2002).

10.2 Cereals in World Food Security

The world's populace is anticipated to increase from 7.4 billion at the moment to 10.0 billion by 2055. The anticipated growth in standards of life, urbanization, rising animal food demands and energy from crops, this needs a considerable increase in grain yield to ensure durable food security at cheap prices (Steduto et al. 2018). The Cereals has always given a significant wellspring of vegetable-protein in human's nourishment. The cereals can effortlessly develop especially on an extensive scale. Nowadays in the world, three central cash-crop cereals are wheat, rice and maize.

10.2.1 Wheat

Wheat *(Triticum spp.),* arising from the Ethiopian Highlands and Levant region of the Nearby Eastern is now cultivated universally. It was utilized to make flour for baked bread and in the long run its utilization spread to cakes, breakfast oat, noodles and pasta. It also supplies as food for domestic animals. In addition, it is utilized in the fermentation procedure to form beer. In England, until the late nineteenth century packs of wheat were used for roofing in the Bronze Age. Wheat consists of fat, protein, carbohydrate and dietary-fiber in the form of starch. Wheat starch itself is thought as a significant commercial by-product and an economic incentive to the wheat-gluten (Cooper 2015).

10.2.2 Rice

Rice *(Oryza sativa L.),* is standout amongst the most significant developed grain crops. Rice is a part of numerous individual's diet throughout the globe, being the primary energy source in certain areas (Gonçalves et al. 2019). Although, being generally used as the origin of carbohydrates, some vitamins, minerals, and other nutrients including fundamental components, rice is also a significant route of arsenic (As) exposure. It is the most significant harvest grown in Asia, giving livelihoods to huge number of farmers. Moreover, In Southeast Asia, both cooked rice grains and prepared rice flour are a significant part of the routine diet (Mwale et al. 2018; Segal and Le Nguyet 2019). Universally the top 5 superior net exporters of rice are Thailand, Pakistan, China, India and Vietnam. As usually, worldwide Asian's gave rise the biggest amount of rice while in Middle East, Latin America and African countries as Ivory Coast, Ghana, Nigeria has shown extensive increment in the consumption and importation of rice (Teye et al. 2019).

10.2.3 Maize

Maize *(Zea mays L.),* is one of the important harvests on the planet. It is cultivated in the vast majority of the temperate and tropical regions of the world. Maize plays an important role to provide energy, proteins and several essential nutrients around the world. We focus on maize, due to the immediate impact of extreme weather on field crops, including the significance of maize as a source of renewable energy. In addition, it is a significant model plant for the scientific community used to analyse various biological processes (Hossain et al. 2019; Romay 2018; Ubilava and Abdolrahimi 2019). It is an immensely valuable cereal crop which provides partially 30% of daily caloric intake to more than 4.5 billion-individuals in 94 developing-countries, where the demand for maize is protruded to double between now and 2050 (Zhao and Yang 2018).

10.3 Abiotic Stresses: Major Constraints of Cereals Production

The existence of extended global-warming and its related climatic anomalies has caused cereals to bear abiotic and biotic stress combinations. Stresses influenced the yield and development capability of crops. Abiotic stress is known as, any environmental circumstance which antagonistically influences the plant's growth, endurance and fertility (Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d 2017, 2018, 2019a, b). This incorporates soil-salinity, extreme temperatures, nutrient deficiencies, alkalinity or acidity, drought, reduced light level, floods and overabundance of ultraviolet radiations etc. These abiotic stresses influence the growth of plant crops by provoking a series of biochemical, morphological, physiological and molecular variations. Abiotic stress establishes severe dangers to crops production by changing the genotype X environment interactions. This prompted changes in a plant's fundamental-metabolism which represented the plant's phenotype. The natural changes in metabolic profiles happens during abiotic stresses essentially include the generation of secondary-metabolites and simpatico solutes, generation of reactive-oxygen-species (ROS) and reducing agents (Fahad et al. 2019b; Singh et al. 2018).

10.3.1 Salinity

Salinity is an abiotic-stress which antagonistically influences crops development and yield. A saline soil has more aggregation of soluble-salts like anions, cations and has a high electrical conductivity. The salinity issue is more frequent in semi-arid and arid areas where evaporation is increased and precipitation is decreased, through which salts lead to the root-zone by capillary rise. In coastal regions, salinity may also happen because of sea-water interruption (Fahad et al. 2019a).

10.3.2 Drought

Drought is one of the most crucial problems being faced by the plants worldwide, not getting much water tends to make plants malnourished. The intensity of the impact of drought are especially intense during the anthesis and grain-filling periods, bringing about declines in the two most important yield components, viz grain number and grain size. Drought during vegetative development and before beginning of flowering, can lessen production by decreasing the development of photosynthetic and storage organs. Moreover, drought may also considerably affect the chemical structure of the grain including the dietary fiber content (arabinoxylan, β-glucan), storage proteins (gliadins, glutenin's) and structure. Basically, drought stress is considered to lessen the carbohydrate content (counting sucrose and starch) of the grain and to expand the protein content (Rakszegi et al. 2019; Shah et al. 2019).

10.3.3 High Temperature

High temperature is the basic trouble for wheat crop in South-Asian countries like Pakistan, Nepal, Bangladesh and India. High temperature is likewise in-charge of heavy pre-harvest and post-harvest damages like scorching of sprigs and leaves, sunburns on stems/leaves/branches, leaf abscission and senescence, shoot and root development hindrance. As per worldwide assessments, due to these changing climatic conditions, yield loss in farming harvests is because of various abiotic-stresses. Over the next 50 years, normal worldwide-temperature is predicted to increase by about 2 °C, making cereals producing areas less appropriate for agriculture (Iqbal et al. 2019).

10.4 Plants Response to Abiotic Stresses

In plant life time, it experiences many different adverse conditions including biotic and abiotic stresses (Fig. 10.1) (Thomashow 1999; Zhu 2002). Plants are subjected to respond to these conditions to protect themselves and for this purpose plants have different functional and biochemical processes. The plant's reaction to these stress signals occur in the form of different signalling pathways that tend to render a response against those stresses (Knight and Knight 2001). During these responses, the signalling pathways for specified stresses have an overlap of different genes expressed during that response (Chen et al. 2002; Chinnusamy et al. 2004; Seki

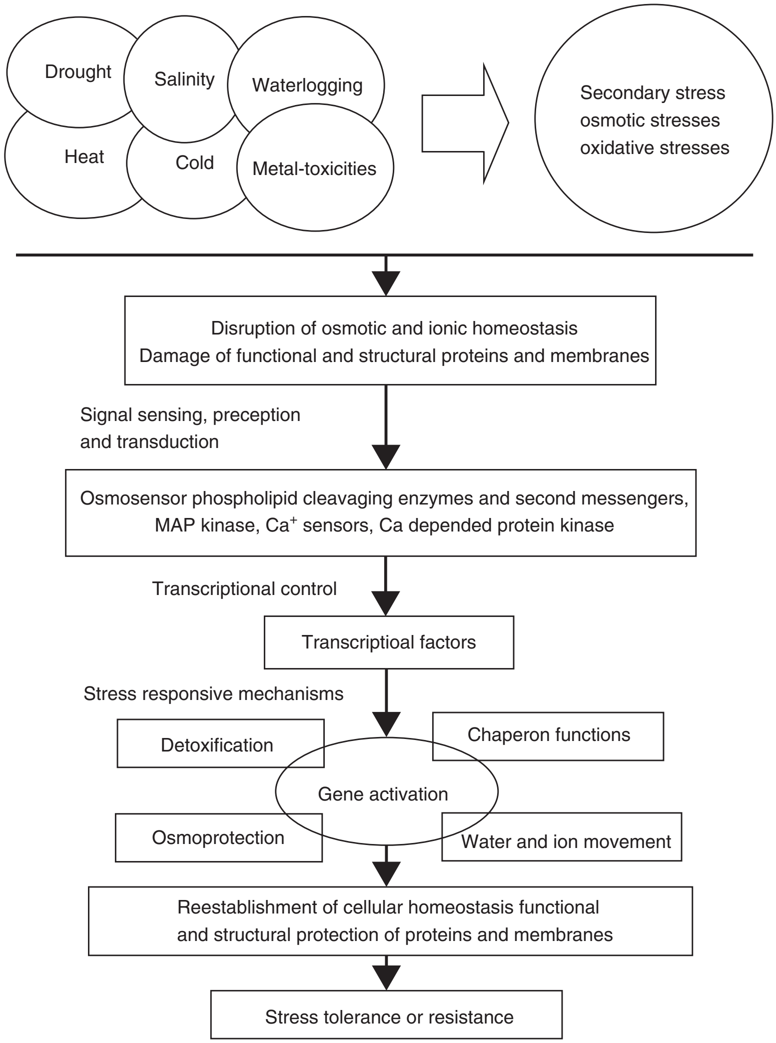

Fig. 10.1 Response of plants to abiotic stresses (Roy et al. 2011)

et al. 2001). The genes that are expressed in plants upon application of any abiotic stress are classified into the following groups:

1. The genes that are responsible for encoding such products that help in direct protection of plant from stresses such as heat stress proteins, osmoprotectants and anti-freeze proteins etc.
2. The genes that take over the transcriptional machinery of the plant such as mitogen activated plant kinases (MAPK) and SOS kinase etc.

3. The genes that are responsible for up-taking of water or ions followed by their transport such as ion transporters and aquaporin proteins (Shinozaki and Yamaguchi-Shinozaki 2000; Wang et al. 2003)
4. Different target genes have been recognized that are related to the abiotic stress tolerance among various plants. These genes are identified and studied using different techniques including transgenesis, mutational studies, knock-ins and in-vitro studies.

10.5 QTL Mapping Techniques, Approaches and Populations

10.5.1 Techniques: PCR Based (SSR Markers) vs. NGS Based (SNPs)

Molecular markers are inevitable tools used for marker assisted breeding (Wang et al. 2019). The SSRs (Simple-Sequence-Repeats) and SNPs (Single-Nucleotide-Polymorphism) markers give detection of changes in DNA between closely related individuals and detect changes even in single nucleotides at whole genome level (da Silva et al. 2019). Most famously used PCR-based markers are Microsatellites or SSR markers. These markers are strongly utilized across plant species for screening, characterizing and evaluating the genetic diversity in several crop-species, as they are co-dominant, locus specific, hypervariable and multi-allelic (Jasim Aljumaili et al. 2018). In maize, SSRs are viewed as most appropriate markers for developing genetic-linkage-maps and assessing the QTLs due to their higher level of co-dominant and allelic-variation nature. SSRs are also considered in wheat varieties, as it's effective because of high levels of genetic polymorphism and phylogenetic relationships. In rice, these markers can be efficiently utilized for producing unique DNA-profiles of rice genotypes due to higher level of information and polymorphism (Abbasov et al. 2018; Choi et al. 2019; Jasim Aljumaili et al. 2018). However, SNP is the most copious kind of DNA variation in many species. A SNP which is common in one geographical-group might be significantly more rarer in other, by means of statistical analyses it relegates an allele frequency and determine the presence of this SNP in all populace (Espiñeira and Santaclara 2016). The presentation of next generation sequencing (NGS) together with high throughput genotyping innovation, makes it moderately simple to identify and utilize SNPs (Shah et al. 2018). SNPs are used to quantify genetic variation in several plant species. The high-throughput sequencing and SNP technique are viable in determining the maps and genome polymorphisms among candidate genes and allele associations (Afzal et al. 2018; Ovesna et al. 2018). In generated vast mutant populaces, SNP discovery innovations are extremely helpful for forensic medicine, functional genomics, population genetics, clinical diagnostics, molecular epidemiology and in plant or animal breeding (Taheri et al. 2017). On the other hand, SNP marker technology gives cheap and easily useable molecular-markers for marker-assisted-selection (MAS) in wheat breeding-programmes. Moreover, it is the most plentiful type of markers in rice and in any other genomes (Cseh et al. 2019; Shabir et al. 2017). Compared with SSRs or microsatellites, the SNPs are increasingly reasonable for high throughput automated genotyping-assays (Table 10.1), enabling samples to be genotyped more quicker, smoothly and economically. They have assumed a significant job in genetic diversity evaluation, in development of functional genomics, high density genetic-maps, gene localization, correlation analysis, species identification and molecular marker assisted breeding. Previous investigations have discovered that, for the validation of functional gene mutation, SNP libraries are perfect molecular markers (Wu et al. 2019).

10.5.2 Approaches: Linkage Mapping vs. Association Mapping

Two common and effective schemes used for detecting new genes, linked with a certain trait are called Linkage mapping and Association mapping (Wang et al. 2018). In crop species, the real techniques for analysing of complex-traits include association mapping of germplasm collections and family-based linkage mapping. Association-mapping has three benefits compared to conventional-linkage-mapping: (I) It reduces cost and time of development of reasonable segregating-populaces and through utilizing existing-populaces there can be a wide variety of materials. (II) It is capable to find multi allelic variations and in a single analysis it serves to recognizes the favourable-alleles linked to a target trait. (III) Its high resolution is very dominant for fine-mapping of quantitative trait loci (QTLs). On the other hand Linkage mapping can identify QTLs with low allelic frequencies (Wang et al. 2018). Recent research has demonstrated that association-analysis is an efficient technique for mining favourable alleles. For instance, linkage analysis is more efficient for species study with low genetic diversity as compared to association analysis.

Table 10.1 SSR markers VS SNP markers

SSR markers	SNP markers
Highly polymorphic and highly transferable	Cheap and easily useable
PCR-based markers	NGS-based markers
Highly reproducible	Increasingly reasonable for high throughput
Co-dominant, hyper variable, locus specific, strong markers and multi-allelic	Helpful for functional genomics, clinical diagnostics, forensic medicine, population genetics
These are tandem repeat motifs	For prediction achievement, three times higher SNP density is required than SSR
Present in both prokaryotic and eukaryotic genomes	Used to quantify genetic variation
Useful in molecular profiling	Used to look at genome variation
Have multiple alleles and subsequently contain more information	Enabling samples to be genotyped quicker, economically and smoothly

However, for cross-validation combination of complementary methods, linkage mapping and association analysis can be utilized (Shi et al. 2017). However, traits such like grain yield attributes, flowering and grain production traits, grain quality traits, drought tolerance traits, salinity tolerance traits, high-temperature stress tolerance were all mapped by association mapping technique (Pradhan et al. 2019). As a result of comparison, linkage mapping has moderately low false positive rate and high power, while association mapping has generally high resolution. For distinguishing QTLs, the traditional approach Linkage mapping is used. Association mapping including candidate gene, genome-wide and regional association, was initially utilized in animals and humans and also acquainted to plants in recent years (Li et al. 2014). At the point, linkage and association mapping approaches works together, it gives an amazing technique for QTL identification and the identity of molecular markers to prompt deployment in breeding (Emebiri et al. 2019).

10.5.3 Populations: F2 Population, RIL Population, Double Haploids

The simplest type of a mapping populace is an accumulation of F2-plants. This populace was the substructure for the Mendelian laws (1865) in which the foundations of exemplary hereditary qualities were set. Two pure-lines consequence from artificial or natural inbreeding were picked out as parents, the parent 1 (P1) and the parent 2 (P2). Instead, to avoid any residual heterozygosity, the doubled haploid-lines can be utilized. The level of polymorphism can be evaluated by molecular markers at the nucleic acid stage or at the phenotypic level e. g. disease resistance, morphology. F2 populations are the result of one-meiosis, in which the hereditary material is recombined. It is a drawback that F2 populace can't be effectively protected, since F2-plants are often not immortal. Different crosses are responsible for comprising of F2 population, these crosses came from recombinant-inbred-lines (RILs) and Doubled-haploid (DH) populaces. DH populaces can be utilized to identify the dominant and additive impacts of QTL-mapping. Moreover, equated with DH and RILs populaces, F2 populaces are genetically as well as instructive as an F2 populaces and have a very diverse genetic background. Hence, F2 populaces are perfect systems for analysing the hereditary foundation of cereal production and its segments in maize and the subsequent data can be instantly utilized for maize-breeding (Zhang et al. 2014). RILs are the homozygous, autonomous or sib mated-progeny of the mortals of an F2 populace. RIL conception for mapping the genes was primitively originated for mouse-genetics. In plants, RILs developed through selfing, except if the species is totally self-incosistent. As in the selfing-procedure, one seed of each line is the origin for the next generation. RILs are also named as single-seed-descent-lines. The major benefit of RIL is that, in the research community these lines comprise a lasting resource that can be used by many groups and can be replicated indefinitely. Before homozygosity, RILs undergo many-rounds of meiosis and the RILs degree of recombination is much higher as compared to F2 populace which considered as another benefit of RILs. Accordingly, as compared to maps generated from F2 populace, RIL populace demonstrates a high-resolution and map perspectives of even firmly linked-markers can be found out. In plants, the RILs are accessible for several varieties, like oat and rice (Schneider 2005). DH lines originate from F1 lines and have been used to do QTL analysis. DH individuals use for QTLs analysis and has been examined with regards to selfing populaces of plants. DH technology provides a layout of benefits in maize-genetics and breeding as pursues: 1st, it's importantly abbreviates the breeding-cycle by growth of totally homozygous-lines in 2 or 3 generation and 2nd, it improves coordination, admitting needing short time or labour and fiscal resources for growing new DH-lines as compared with the conventional-RIL populace exploitation process (Choi et al. 2019; Martinez et al. 2002).

10.6 QTL Mapping: Current Achievements or Success Stories

To minimize the effects of abiotic stress patterns in a plant's life, different mechanisms and procedures have been used, following are the QTLs that have been detected and mapped for crops improvement:

10.6.1 QTLs for Drought Tolerance

To minimize this damage, many QTLs have been discovered by the use of molecular genetics techniques which either increase the yield of the plant under stress or increase the expression of the traits or genes that have the tendency to tolerate drought conditions. These genes can either be useful as candidate sequences for QTLs or as a transgene (Cattivelli et al. 2008; Forster et al. 2004). In maize (*Zea mays L*), to map a linkage between the genes for quantitative traits and the molecular markers, the restriction-fragment-length-polymorphism (RFLP) is used. The region of the genome that is controlling the tolerance of the maize plant to drought stress is found on the chromosomes 1,3,5,6 and 8. In recent studies, overall 45 QTLs were detected for yield and yield components under drought stress conditions (Agrama and Moussa 1996; Nikolic et al. 2013) (Table 10.2).

The production of crops can be enhanced by changing the root system of the crop, bigger root system will be minutely influenced by the scarcity of water supply (Manschadi et al. 2010). QTLs have been recognized and mapped for the effectiveness of water use and the root ratio by depth in crops (Hamada et al. 2012; Spielmeyer et al. 2007). *Moroberekan* is a rice genotype with drought tolerance due to its long and thick root system allowing the plant to extend its roots down to the depths of the

Table 10.2 Different traits of maize crop consisting of number of QTLs detected on different chromosomes for drought tolerance (Nikolic et al. 2013)

Cereals	Traits	No of QTLs	Chromosomes
Maize	Grain yield	5	(2,5,5,7,10)
	Number of rows per ear	5	(1,1,5,5,10)
	Number of kernels per row	7	(3,3,4,4,5,7,7)
	1000 kernels weight	5	(1,1,2,7,10)
	Ear length	5	(2,3,3,8,10)
	Ear diameter	5	(3,4,5,5,7)
	Kernel length	2	(5,7)
	Kernel width	6	(1,2,2,2,6,7)
	Kernel thickness	5	(2,5,7,8,10)

Table 10.3 QTLs for wheat crop with drought tolerance with their specificity (Bharti et al. 2014; Malik et al. 2015)

Specificity	QTLs
For angle of roots	QRA. qgw-5D
	QRA. qgw-3D
	QRA. qgw-2A
	qRN. qgw-1B
For length of roots	QRl. ccsu-2B.1
For dry-weight of roots	QRdw. ccsu-2A.1
	QRdw. ccsu-2A.2
Associated with rate of photosynthesis, stability of cell membrane	QPn2AC
	QCMSa2AC
	QCMSa2AC

land layers to get water. Around 50% of the QTLs linked to the root characters were found in this genotype of the rice (Champoux et al. 1995; McCough and Doerge 1995). Different QTLs that have been mapped so far, have their own distinct characteristics. The QTLs that have affected the angle of the roots are QRA. qgw-3D, QRA. qgw-2A and QRA. qgw-5D while the QTL for the number of roots is qRN. qgw-1B. These QTLs were mapped in wheat crop for the tolerance of drought stress (Christopher et al. 2013). For the length of the roots the QTL identified is QRl. ccsu-2B.1, for the dry-weight of the roots the QTLs are QRdw. ccsu-2A.2 and QRdw. ccsu-2A.1 these QTLs are found in chromosome 2a and 2b of wheat crop, respectively (Bharti et al. 2014). The QTLs associated with the rate of photosynthesis, stability of cell membrane and the relative water content of the crop are QPn2AC, QCMSa2AC and QCMSa2AC, respectively (Malik et al. 2015) (Table 10.3).

10.6.2 QTLs for Salinity Tolerance

Presence of surplus salts in the soil where plants are present tend to drastically affect the plant yield, growth and its metabolic activities (Lutts et al. 1995). Salt stresses affect the crop germination rate, eliminate the seedling survival, destruct chloroplast structure and reduces photosynthesis to nearly zero and also decrease the grain yield (Asch et al. 2000; Kazemi and Eskandari 2011; Yamane et al. 2015). In wheat, QTL for sodium (Na^+) exclusion has been mapped on 2A chromosome (Lindsay et al. 2004). Sodium tolerant QTLs mapped in rye are OsHKT1;5 and TmHKT1;5-A and a QTL in wheat is TaHKT1;5-D (James et al. 2006) (Fig. 10.2). Wheat trihelix genes responded to several abiotic stresses particularly salt and cold stresses. The trihelix gene family is a plant's particular transcription factor family which played important roles in plant growth, development, and reactions to abiotic stresses (Xiao et al. 2019). According to recent studies, Four QTLs related with salinity tolerance for STI(NL) were identified on the chromosomes (3A, 4B, 5A, 5B, 6A and 7A). Two QTLs, STI(LL) and STI(RL) identified on 5A and 5B chromosomes. QTLs for salinity resistance were identified for several parameters. For example, a single QTL for %DL explicated 13% of the phenotypic variation on chromosome 4B. 3 QTLs for STI(NL) were identified: 1st on 3A-chromosome explicating 17% of the phenotypic diversity, 2nd on chromosome-5A showing 15% of the phenotypic diversity and 3rd on chromosome-5B presenting 13% of the phenotypic diversity. QTL for STI(NL) covered the QTL for STI(CHL) on the similar chromosome-3A. 3 QTLs for STI(RL) were identified: 1st on 3A-chromosome explicated phenotypic variation of about 20 %, 2nd on 5B chromosome showing phenotypic variation of about 15 % and 3rd on 6A chromosome presenting phenotypic variation of about 17% (Turki et al. 2015).

In rice, a QTL that is salinity tolerant is mapped named as qNaSH8.1 while sodium and potassium concentration are controlled by a QTL on chromosome number 9 which are qSKC9 and qSNC9 (Pandit et al. 2010; Xu et al. 2012). Furthermore, in maize 41 QTL associated with salt tolerance at the seedling-phase were detected. Between them, 13 QTLs which includes qRLS1, qFLR1, qSLR1-1, qRFR1, qSLS1-2, qFLS1-2, qRFS1, qSFS1, qFFS1, qFDS1, qRLR1, qSFR1-1, and qFFR1 explained freely >21% of the phenotypic diversity in their respective traits. Nine important QTLs (qRLS1, qRFS1, qSFS1, qFFS1, qSLS1-2, qFLS1-2, qFDS1, qRLR1, and qFLR1) co-situated to the similar chromosomal part, explaining that this QTL area had pleiotropic consequences and assumed an important role in controlling salt resilience in maize seedlings. These 9 QTLs covered with some other 4 co-located big impact QTLs (qSLR1-1, qSFR1-1, qRFR1, and qFFR1) that explicated >22% of the phenotypic diversity in their particular traits (Luo et al. 2019) (Table 10.4).

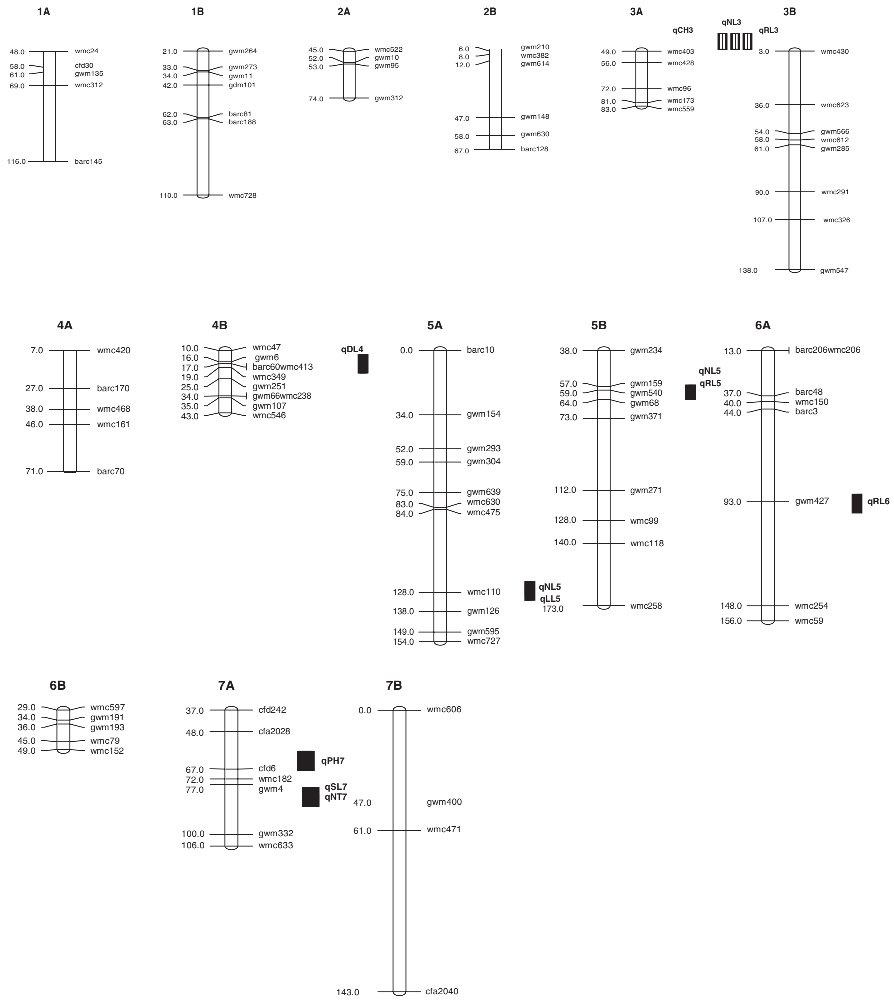

Fig. 10.2 Positions and names of QTLs detected in wheat for salinity tolerance (James et al. 2006; Lindsay et al. 2004)

10.6.3 QTLs for Heat and Cold Tolerance

High and low temperatures are both regarded as the extreme temperature conditions that a crop has to tolerate, and these two conditions can severely damage the crop. Increasing temperature of the earth due to global warming has been the prime abiotic stress that a plant has to face (Wahid et al. 2007). High temperature stress makes the tapetal cells to go into early abortion stage which leads to pollen sterility (Parish et al. 2012). Many QTLs have been mapped based on the stress generated by the high and low temperature. During the flowering stage of the rice, four QTLs

Table 10.4 QTLs for salinity tolerance in wheat, rice and maize. In wheat, QTLs names and positions are described in Fig. 10.2

	QTLs	Chromosomes	References
In wheat			
Sodium tolerant	TaHKT1;5-D	–	James et al. (2006), Lindsay et al. (2004)
	10 QTLs	3A	
		4B	
		5A	
		5B	
		6A	
		7A	
In rice			
	qNaSH8.1	–	Pandit et al. (2010), Xu et al. (2012)
Sodium, potassium tolerant	qSKC9	9	
	qSNC9		
In maize			
	qRLS1, qFLS1-2, qSLS1-2, qRFS1, qFFS1, qSFS1, qRLR1, qFDS1, qSLR1-1, qFLR1, qRFR1, qSFR1-1, qRLS1, qFFR1, qFLS1-2, qSLS1-2, qRFS1, qSFS1, qFDS1, qFFS1, qRLR1, and qFLR1, qRFR1, qSLR1-1, qSFR1-1, and qFFR1	–	Luo et al. (2019)

were mapped which were related to heath stress tolerance. These QTLs are qhr1, qhr3-1, qhr4-3 and qhr8-1. Spikelet fertility is controlled by two QTLs named as qHTSF1.1 and qHTSF4.1 (Talukder et al. 2014; Ye et al. 2012, 2015). The low temperature stress also damages the physiology and normal functions of the plant. It also interferes with the seed germination, growth, nitrogen content, weight of shoot etc. and cause freezing injuries (Andaya and Mackill 2003; Jompuk et al. 2005; Thomashow 1999). In rice, QTLs mapped for low temperature tolerance at booting phase are qCTB7 and qCTB8 (Kuroki et al. 2007; Zhou et al. 2010). Other QTLs mapped for cold temperature tolerance include qLTG3-1, qLTG11-1 and qLTG3-2 which controls the germination of seeds under low temperature (Satoh et al. 2016). In maize, six QTLs on chromosome 4,5,6,7, and 9 were mapped that were belonging to germination at low temperature and root length in this cereal. Because of low temperature, male sterility is brought on at reproductive phase and badly affects the production of essential cereals. So, 2 QTLs (qCTR5 & qCTR12) were identified on chromosome 5 and 12 of maize genome which control this trait at reproductive phase. The major QTLs identified, named 4A-1, and were founded on the long-arm of chromosome 4 (Ahmad et al. 2018). However, in wheat, two QTLs (QHst.cph-3B.2 and QHst.cph-3B.1) were mapped that were responsible for heat tolerance (Sharma et al. 2017) (Table 10.5).

Table 10.5 QTLs for Heat and cold tolerance in rice, maize and wheat

	QTLs	References
In rice		
Heat stress tolerance	Qhr1	Andaya and Mackill (2003), Jompuk et al. (2005), Talukder et al. (2014), Thomashow (1999), Ye et al. (2012, 2015), Kuroki et al. (2007), Satoh et al. (2016), Zhou et al. (2010)
	qhr3-1	
	qhr4-3	
	qhr8-1	
Control spikelet fertility	qHTSF1.1	
	qHTSF4.1	
Low temperature tolerance at booting phase	qCTB7	
	qCTB8	
Cold temperature tolerance	qLTG3-1	
	qLTG3-2	
	qLTG11-1	
In maize		
	qCTR5	Ahmad et al. (2018)
	qCTR12	
	4A-1	
In wheat		
	QHst.cph-3B.2	Sharma et al. (2017)
	QHst.cph-3B.1	

10.6.4 QTLs for Waterlogging Tolerance

Waterlogging is a condition when surplus quantity of available water covers only root system of plants rather than all plant or stem. Logging is responsible for displacing of plant stem from upright position permanently. It's a very serious problem in cereals and because of severe logging entire cereal field is compromised causing big loss to the crop production. Logging stress is responsible for reducing the yield and quality of cereals by breaking or bending of stem. Regardless of other abiotic stresses traits, only a small work has been done for the betterment of logging resistance in cereals. Waterlogging resistant QTL (lrt5) was detected in rice under Typhon conditions. Submersion QTL (SUB1) has also been reported in rice. From the fine mapping of this QTL a bunch of submersion genes (SUB1A, SUB1B, and SUB1C) were identified. In maize, a submergence related QTL (Subtol6) has been reported on chromosome 6 (Ahmad et al. 2018). Composite interval mapping in wheat has detected 48 QTLs which are grouped in 10 genomic regions substantial across both field and greenhouse experiments. These clusters were identified on chromosomes 1BS, 1BL, 1D, 2A, 2BS, 3B, 5A, 5B and 6D with single QTL explicating from 4 to 33% of the phenotypic variance. Out of 48 QTLs, 35 were identified under water logging stress and 13 under control conditions. Out of 10 QTLs

Table 10.6 QTLs for water logging tolerance in rice, maize and wheat (Ahmad et al. 2018; Ballesteros et al. 2015; Sharma et al. 2017)

	QTLs	Chromosomes
In rice		
Under Typhon conditions	QTL (lrt5)	–
Submersion	QTL (SUB1)	–
Cluster of submersion genes	SUB1A	–
	SUB1B	
	SUB1C	
In maize		
Submergence related	QTL (Subtol6)	6
In wheat		
	35 QTLs	1BL
	2 clusters	6D

clusters, 2 were adaptative to water logging stress placed on chromosomes 1BL and 6D and comprised no QTL for the control treatment (Ballesteros et al. 2015) (Table 10.6).

10.7 Conclusion and Future Perspectives

Under the climate chage scenario, plant species have always been affected by different stresses including biotic or abiotic. Abiotic stresses like low and high temperature, excessive salt, drought conditions and waterlogging heavily affect the plants growth and yield worldwide. Scientists are using different approaches to overcome these problems and to make the plants more resilient to these conditions. So, their growth, development and yield shouldn't be affected as much. Mapping of quantitative trait loci (QTL) brought a revolutionary breakthrough in the world of crop production. QTL identification and mapping has made it easy for the plant breeders to increase the crop productivity and yield. There has been some great advancement made through QTL analysis in areas of plant science developments. Even it had a fair share in the revolution of quantitative genetics. Therefore, it has been concluded that QTL mapping will play pivotal role in abiotic resistance crops production in future. For the plant breeders, there is a dire need to integrate all the QTLS responsible for resilience of crops under changing climate through genomic selection and hence reduce the time for the climate-resilient variety development.

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Chapter 11
Effectiveness of Conventional Crop Improvement Strategies vs. Omics

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Abstract World's population is increasing exponentially and it is expected to be doubled by the year 2050. In many developing countries and rural areas, malnourishment is also making the condition worse. Conventional crop improvemnt strategies e.g. breeding have been used by farmers since ages, but these approaches are not well efficient to get our targets of having more yield, high quality and nutritional food to feed the rapidly growing population. In this chapter, we have summarized the importance and use of Omics-based strategies e.g. genomics, transcriptomics, proteomics, metabolomics and interactomics, for crop improvements. Omics based approaches have opened the doors to improve the varieties with high yield and enhanced nutritional value, together with herbicide and other stresses resistance ability By overcoming few challenges related to the application of Omics in agriculture, this could be the best option to confront with the current needs and future food demands of the exceeding population.

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_11

Keywords Genomics · Transcriptomics · Proteomics · Metabolomics · Crop improvement

11.1 Introduction

Agriculture is the science and art of cultivating wild plants for the use of humans. Since 10,000 years ago, ancient people made the transition from foraging to harvesting crops and many crops have been cultivated. Food is vital for human life on this planet. World's population is increasing rapidly with every passing year. According to an estimation, the food production must be increased up-to almost 70% to meet the need of the growing population and increased food consumption (Rashid et al. 2017). Enough food production for a rapidly growing population has been facing many challenges like; shortage of water, climate change due to global warming and a decrease in available land for agricultural purpose due to rapid urbanization. The need of the hour is to produce efficient high yielding crops which can feed this rapidly increasing population. Crop improvement basically refers to the genetic alterations of the plants to satisfy the food requirement of the growing population. Crop improvement has a history which is as old as the history of agriculture. Since the start, man has been trying to manipulate different ideas and techniques to save the crops from different diseases by using conventional methods (Sinclair et al. 2004). Conventional breeding technologies have been extensively used to improve crops productivity, but these technologies are more time consuming and less efficient. Unfortunately, conventional breeding techniques were no more viable to cope with the current needs. With an alarming increase in the world's population, there is a need to develop new approaches to improve the quality and quantity of yield. New methods have been introduced for better production, improved nutrient content and disease resistant crops.

In this era of technology, recent innovations have opened up new horizons in the field of agriculture. Several viable techniques like; changing genotype, mutagenesis, genetic engineering, proteome profiling and many others have helped us in the development of stress-tolerant crops (Rashid et al. 2017). This chapter aims to provide an overview of conventional technologies which were used in the past and omics-based strategies i.e. genomics, transcriptomics, proteomics metabolomics and interactomics for crop improvements. Moreover, implementation of these techniques in different areas of agriculture, their benefits and limitations, current challenges and future insights will also be discussed (Abdallah et al. 2015; Kamthan et al. 2016).

11.1.1 The History: Revolutionary Era in Agriculture

Different inventions transformed the agriculture sector completely in late nineteenth to early twentieth centuries. The mechanical revolution of the 1890s was pushed forward by the invention of the cotton gin, reaper, thresher and many new advancements for harvesting. It helped farmers to produce an increased amount of grain per acre planted and effective use of land with less labor. Then during the first half of the twentieth century, development of the Haber Bosch process, by the German chemists Fritz Haber and Carl Bosch, made it possible to produce ammonia from hydrogen and nitrogen artificially. This led to the production of nitrogen fertilizer which boosted the crop production in less time. This was the era of the chemical revolution which helped to increase the crop yield with the same amount of land and seed. Right after the chemical revolution, in the United States, there was a spectacular increase in farm productivity and decrease in farmland. One of the astonishing achievements in the past decades was the production of hybrid corn in 1930 which dramatically increased the corn production. This brought the hybrid revolution in agriculture. In a very short time, this hybrid technology was broadened to other crops. Advancements in technology gave rise to these revolutions, which helped the consumers and farmers of industrialized countries. The second half of the twentieth century brought the 'Green Revolution', a different kind of agricultural advancement, concentrated in developing countries with traditional agriculture (Wu and Butz 2004).

11.1.2 The Green Revolution

The term Green Revolution refers to the era of agricultural advancements beginning in Mexico in the 1940s. Beginning of this revolution is attributed to an American scientist, Norman Borlaug. He started his research in Mexico and produced high-yield producing wheat with higher disease resistance (Khush 2001). Due to the great success of this revolution, his advanced technologies were adopted by scientists worldwide during the 1950s and 1960s. After the Second World War, there was an urge to produce more food because many people in those affected areas were facing food insecurity. High yield variety (HYV) crops which were superior to other local crops, having high grain quality, yield stability, short growing season, resistant to biotic stresses were used to cope with the challenge of food insecurity. It saved massive malnutrition in many developing countries (Pingali 2012; Wu and Butz 2004).

11.2 Conventional Strategies for Crop Improvement

Since the beginning of agriculture, farmers have been using different strategies to alter the crops they grow. Their conventional strategies helped them to produce the best fit crops. One of the famous strategy that has been used extensively is conventional breeding. Conventional breeding can be defined as producing the best cultivars by using old breeding methods within natural boundaries. So, in this process breeders construct best fit cultivars by assembling specific traits including higher yields, disease resistance, sweet fruits, and faster growth from closely associated plants (Acquaah 2015).

11.2.1 Pure-Line Selection

This is much common and conventional breeding procedure, to cross-breed two pure-lines (closely related) having desirable traits. Then progeny row is grown from every selected plant for further analysis of the desirable traits. After using pure-lines for a crossover the resulting progeny is further screened for desired characteristics like yielding capacity and agronomic importance. Therefore the development of valuable cultivars (having high yield or improved quality) and increase in Homozygosity lend an advantage to the use of this technique (Willoughby et al. 2019).

Limitations It only separates superior genotypes and doesn't produce new genotypes. While it is only restricted to self-pollinated crops. Inbreeding depression may occur due to the use of two closely associated lines, it occurs when the genetic material of both the parents is similar due to which some recessive deleterious genes express in the resulting progeny and make them unfit. These inbred cultivars will be more prone to many genetic disorders (Willoughby et al. 2019).

11.2.2 Hybrid Breeding

A breeding program in which individuals from two different lines are selected for a crossover, and it can be intraspecific (cross within same species) or interspecific (cross within different species) (Agrawal 1998). The resulting hybrid progeny shows an increased function of desired traits referred to as heterosis or hybrid vigor (Reif et al. 2005). These hybrids will be more vigorous, show faster growth and more reproductive output as compared to their parents (Goulet et al. 2017). Moreover, these are relatively more tolerant to different biotic and abiotic stresses. Hybridization can also arise new species of same ploidy or different ploidy levels.

Limitations One main problem associated with hybridization technique is that it will stop the evolutionary process or some varieties of species will extinct due to intraspecific or interspecific crosses. This may result in the loss of particular genes from the genetic pool. Moreover, there will be no control over the genetic mutation because the genetic makeup of both parents will be different so new recombination may lead to unknown mutations (Goulet et al. 2017). Inbred progenies will be less stable in adverse conditions like stresses and diseases than a diverse population. Furthermore, due to monomorphic nature for most genes, these lines will not have the capacity for long term adaptation (Schumer et al. 2013).

11.2.3 Population Breeding

Population breeding is used to improve the phenotypic performance of the crops by enhancing the frequency of favorable alleles, controlling trait of interest (Breseghello and Coelho 2013). A series of selection and recombination cycles are imposed on an intermediate-sized population. It is impossible to generate a perfect genotype with all the selected favorable alleles in the only single cross because most economic traits are quantitative in nature. Therefore to generate new genotype of all the desired phenotypes a series of selection and recombination is performed on intermediate or large population size. In return, it increases the probability of producing new genotype with a high proportion of favorable alleles (Viana et al. 2013). It allows breeders to create new genotypes/new populations which would be a combination of all the desirable alleles (Breseghello and Coelho 2013).

Limitations This breeding scheme can only be applied in large and effective population size. While in small population size it may lead to depletion of genetic variance and slows down genetic gain (Falk 2010).

11.2.4 Pedigree Breeding

In this method different cultivars are obtained from self-pollinating species. It basically involves crossing parents (having desirable characteristics). Selection events are maintained to get separate inbred lines. These inbred lines will have favorable characteristics of both parents (Breseghello and Coelho 2013). This method is effective for those trait which are quantitative in nature, controlled by more than one gene for example disease resistance trait, and specific shape and color of plants.

Limitations The major limitation of this method is, no possibility to estimate the total yield during the process. It can only be evaluated at the end of breeding process when seed is ready. Moreover success potential in terms of yield by using this scheme is very low almost 1% per year (Breseghello and Coelho 2013).

11.2.5 Constraints in Conventional Breeding Programs

The conventional breeding technique has its advantage as it is technically less complex, quite cheap and free from governmental limitations. But various factors limit the advantages of conventional breeding with the major effects arising from the limitations of the sexual process itself and include limitations on the genetic variation within the selected crop (Manshardt 2004). Although these traditional breeding programs were the main contributor to the production of main foods during the green revolution. These techniques are unable to improve the quality of the food more than to a particular level due to several limitation factors. In spite of giving some benefits, conventional approaches also left many agricultural, human health, socioeconomic and environmental challenges. Furthermore, a large number of the population is required to combine the diverse traits of both parents. It also takes multiple cycles of segregation and selection to get that unique progeny which would have a combination of all favorable traits (Manshardt 2004; Wu and Butz 2004).

11.3 Omics-Based Strategies for Crop Improvement

Since over the last decade, a major advancement in the field of biology has been observed. New technologies have arisen and permitted us to monitor the thousands of cellular molecules with a single analysis. These new strategies which have been used to measure the cellular molecules such as RNA, protein, and metabolites of different pathways are termed as Omics based technologies (Vailati-Riboni et al. 2017). Omics derived from 'ome' aims at the collective identification and characterization of biological molecules. Omics itself is the combination of genomics, transcriptomics, proteomics, metabolomics and interactomics as shown in (Fig. 11.1). So, these technologies provide a complete and quick assessment of biological activity and genetic differences among different individual and species (Horgan and

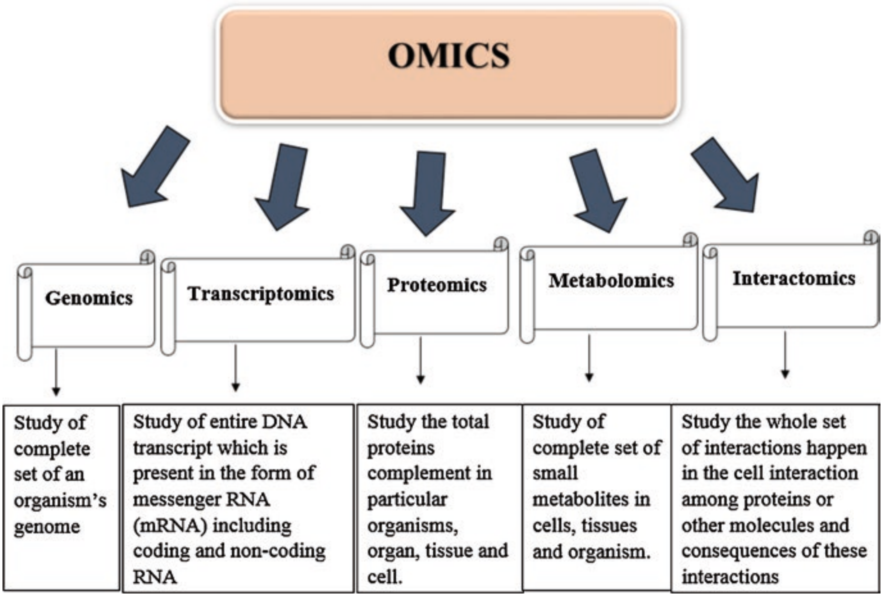

Fig. 11.1 An overview of OMICS-based strategies

Kenny 2011). These high throughput technologies have provided an essence to identify those genes or their products which are directly involved in grain production and responsible for the agronomic phenotype. Furthermore, it revolutionized crop breeding and helped in the identification of novel alleles from diverse sources.

11.3.1 Genomics-Based Strategies

Genomics is the most mature field of Omics. It involves sequencing and analysis of the complete set of an organism's genome. Genomics mainly focuses on identifying the genetic variants associated with a particular trait. Many advances in genomics like DNA sequencing techniques, use of markers and genome selection helps in sequencing the genome of most crop if not all, in the most affordable and convenient way. Firstly, there were a lot of questions regarding crop genomics, but these questions became vague when plant and crop genome sequencing started and completed. Genomics is providing advanced ways, which combines the functional genomics and improved phenotyping assays, for crop breeding system (Bevan et al. 2017).

11.3.1.1 Genome Sequencing

Genome sequencing has revolutionized biology and also has a phenomenal impact on plant breeding. Genome sequencing of several crops including rice, maize, grape, papaya, cucumber, apple, strawberry, tomato, and peach has been done (Huang et al. 2009; Ming et al. 2008; Shulaev et al. 2011; The International Peach Genome et al. 2013; The Tomato Genome et al. 2012; Velasco et al. 2010). It provides a way to understand the genetic makeup and behavior of different plants, alternatively identification of those genes which are directly associated with yield, tolerant to different stresses and are agronomically important. Identification of agronomically important genes can be further analyzed by the bioinformatics tools and can be directly implemented for crop improvement. Genome sequencing has passed from three main eras of development named as first generation sequencing, second-generation sequencing, and third-generation sequencing (Heather and Chain 2016). Different sequencing techniques were used in different phases of genome sequencing described below.

First-Generation Sequencing Sanger sequencing (Fig. 11.2) is the most widely used genome sequencing method from a long time also known as first generation sequencing. It basically involves the termination of in vitro DNA replication by adding dideoxynucleotide triphosphates (ddNTPs) instead of deoxynucleotide triphosphates (dNTPs). It results in the formation of DNA strands of varying lengths. Next, these sequences can be identified by running on gel electrophoresis which separates

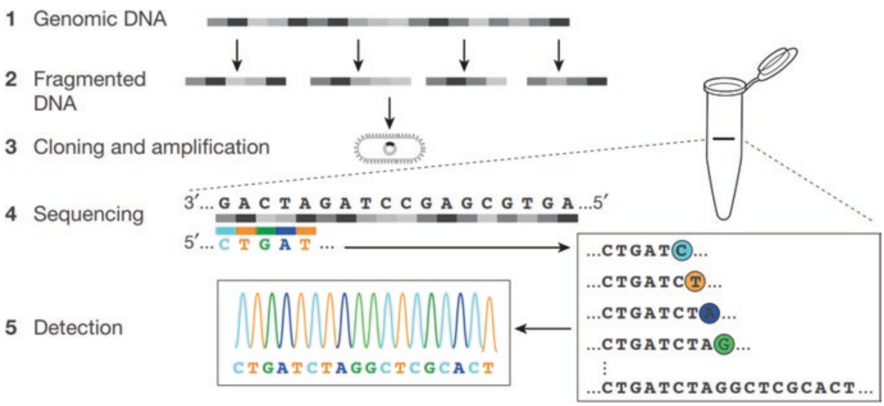

Fig. 11.2 Overview of Sanger sequencing approach (figure is taken from Shendure et al. 2017)

DNA sequences on the basis of their lengths. Afterwards, these sequences are exposed to X-ray film which deduces the order of bases (Sanger et al. 1977).

Second-Generation Sequencing This high throughput technology is being advanced and has the ability to generate a large amount of sequence data. This is also termed as next or second generation sequencing. The first approach of second-generation sequencing is pyrosequencing developed by Roche as GS20. Now currently two ultra-high throughput techniques are being used because of their unbelievable efficiency and speed. One is the Illumina genome analyzer (Bronner et al. 2014), and the other is ABI SOLiD (Sequencing by Oligonucleotide Ligation and Detection) system (Ambardar et al. 2016), some main points discussed below in (Table 11.1).

Third-Generation Sequencing There is a considerable discussion about defining the division from second-generation sequencing technology to the third generation sequencing technology. There are some defining characteristics of third-generation sequencing like Single Molecule Sequencing (SMS), Single Molecule Real-Time sequencing (SMRT), and divergence from previous technologies. As third generation sequencing is the most recent era of genome sequencing it has the advanced sequencing techniques which include SMS sequencing, SMRT sequencing, and Nanopore Sequencing. Helicose Biosciences commercialized the first SMS technology, working of this technique is the same as Illumina sequencing, but amplification step is missing (Bayley 2017). The first time it became possible to sequence the non-amplified DNA, thus avoiding all the biases and errors associated with amplification. It's a relatively expensive and slow process. The most widely used third-generation sequencing technique is Single Molecule Real Time (SMRT) sequencing, provided by Pacific Biosciences (Ambardar et al. 2016). It is an effort to overcome the challenges in the field of genomics. SMRT sequencing technology enables the long-read sequencing, exploits the natural process of DNA replication and real-time

Table 11.1 Comparison of Illumina and SOLiD technology

Illumina genome analyzer	ABI SOLiD system
With the read length of 100 bp, it can generate sequence data of 50 Gbp by using reversible terminator chemistry	This is a ligation-based technology developed by Applied Biosystem (ABI). It can generate data of 60Gbp with the read length of 20-25 bp.
Used for re-sequencing of the genome, transcriptome profiling (RNA Seq) and chromatin immune Precipitation sequencing (ChiP Seq)	Used for resequencing programs but it can also be used for transcriptome analysis and profiling and ChiP-Seq
It has a low error rate, fast, automated, cost-effective and can be applied on large scale sequencing programs by using it.	This approach uses ligation-based detection, not synthesis based so it has fewer chances of error.

observation of DNA synthesis is also enabled by this technique. There are two key innovations upon which SMRT sequencing based: zero-mode waveguides (ZMWs) and other one is phospholinked nucleotides. ZMWs facilitates the illumination of the bottom of the well, containing the immobilized DNA template/polymerase complex. Phospholinked nucleotides facilitate the observation of immobilized DNA complex, during the whole natural replication process. Nanopore sequencing technology was first time offered by the sequencing company, Oxford Nanopore Technologies (ONT). This sequencing technology allows the sequencing of DNA molecules with the length above than 100,000 bp. However, the average length of typical DNA samples ranges between 10,000 and 20,000 bp. Many reports, have recently been published, of genome assemblies produced by using Nanopore sequencing (Shin et al. 2019).

11.3.1.2 Molecular Markers Application

Ongoing advances in DNA sequencing technology and sequenced genome of many crops, allowed to create molecular markers which can cover the entire genome and help in variation analysis (Garrido-Cardenas et al. 2018). Molecular markers permit us fine, cost-efficient, rapid and high throughput identification of genetic variants of various desired traits in crops, based on Marker Assisted Selection (MAS). Markers have been used in breeding programs for many purposes like the development of linkage maps, evolutionary analysis, selection of different alleles and mapping of different genes of agronomic importance. Simple sequence repeats (SSRs) have been used to study the traits associated with seed composition in soybeans like seed oil and protein (Chaudhary et al. 2015). SSRs are also highly used in cereals because of their high reproducibility, polymorphic nature, low cost, usage and co-dominant inheritance. Sequence tagged site (STS) and single nucleotide polymorphism (SNP), which are linked to a specific gene or quantitative trait loci (QTL), are also extensively helpful and applicable in MAS (Davierwala et al. 2001; Bui et al. 2017). A number of genetic markers are now available which are being trended with broad application in breeding programs. MAS helps the breeders to select the parental genotype and selection of those traits which are difficult to measure by phenotypic assays or conventional breeding. Consequently, it helps to select the favorable genes/alleles or increase their frequency in the early breeding program. There will be fewer chances of having unfavorable alleles when breeding process proceeds and ends.

11.3.1.3 Genetic Modifications

Genetic modifications allowed scientists to introduce novel genes in the plants using different methods including direct or indirect approaches. The direct method involves different physical, chemical and electrical treatments to introduce the desired gene while the indirect methods involve the use of *Agrobacterium* as a vector. *Agrobacterium*-mediated transformation method is one of the most frequently used methods for the transformation of desired genes into the plant (Matveeva 2018). Although, these genes are not integrated into the genome (transient transformation) but successfully makes the copies of the desired gene products. To use of this soil gram-negative bacteria as a vector for transformation involves the presence of two different regions in the Ti plasmid; first is T DNA region which comprises of 25 highly conserved sequences at the end of T region. While, second is via genes region which is required for the transformation, integration, and processing of the transgene into the host plant. The transformation process involves removal of T-DNA region except for the borders sequences which demarcate the desired DNA to be transferred into the plant.

Genetic modification and variation in the structure of the gene and its expression can also help to determine its effect on a particular trait. Many qualitative traits have been characterized in a good manner at the genome level, while various other traits which are controlled by multiple genes need more attention. Some of the most widely acceptable direct methods for gene transfer are listed in (Table 11.2).

11.3.2 Transcriptomics Concept and Strategies

Word transcriptomics was first time used in 1990, and it refers to the study of entire RNA set of an organism including messenger-RNAs (mRNAs), coding and non-coding RNAs (McGettigan 2013). Each cell utilizes different genes which express under different physiological condition and developmental process. But in general, tissues express similar genes which can be used to identify the tissue in the absence of any other valuable information. With the expression profiling and comparing, transcriptome can help to predict that when and where the genes express themselves under different treatments. RNA is considered as the intermediate of central dogma process between DNA and protein. Moreover, it is considered as the first read out of the DNA. Transcriptomics study provides insight into all the cellular process in cell and which process is dormant at which stage of cellular activity. There are basically

Table 11.2 Most common direct methods for gene transfer

Methods	Description
Biolistic method	Transfer of DNA into the cell using high-velocity microprojectile microscopic gold coated with DNA also called as a gene gun, and microprojectile bombardment (Tian et al. 2019).
Electroporation	The electric field is used to enhance the permeability of cell or tissue for the delivery of DNA (Batista Napotnik and Miklavcic 2018).
Protoplast transformation	PEG-mediated DNA transfer to the protoplast for transient gene expression (Duarte et al. 2016).
Ultrasound-induced transformation	Direct DNA transfer into the cell, tissue or protoplast using high-frequency ultrasound waves (Lin et al. 2010)
Laser-mediated transformation	Use of laser beams to irradiate sample of cell and make them porous for DNA transformation (Peng et al. 2018).
Nanoparticle-mediated transformation	For the delivery of biomolecules, nanoparticles are the promising material, having the ability to pass through the cell wall without any external force, with adjustable physiochemical properties for conjugation (Cunningham et al. 2018).

two dominant strategies that are commonly used for the analysis of total RNA of a cell one is microarray and other is RNA Seq.

11.3.2.1 Microarray

Microarray measures a defined number of RNA in the cell using the hybridization process (Schena et al. 1995). Since its appearance, it has become the most widely used technique for transcript analysis. It depends upon, immobilized sequence on the array, targets nature for hybridization, and condition for hybridization. Gene expression profiling using microarray usually involves the extraction of messenger RNA (mRNA) and converting it into cDNA (Fig. 11.3). These cDNAs are fragmented into small fragments and fluorescent labels are also attached with these fragments. Hybridization of targets (cDNA) with probe (complementary DNA sequence to targets) in DNA chip takes place. Hybridization takes place pairwise with targets and fluorochromes which are attached to targets. Excitation of fluorochromes and emission of light of different wavelength is recorded. Different treatments and comparison are used to perform expression profiling, which may represent different genotype, organ, tissues, and individual cell type. It can also represent biotic and abiotic treatments sampled at one time or in a series of time (Gul et al. 2016). Appropriate statistical design and analysis is an important key to accurate microarray results. Microarray is being used for many model species and crops, like in plants it has been used for *Arabidopsis thaliana* whose complete genome sequence is available and for many rice varieties which also have their genome sequenced.

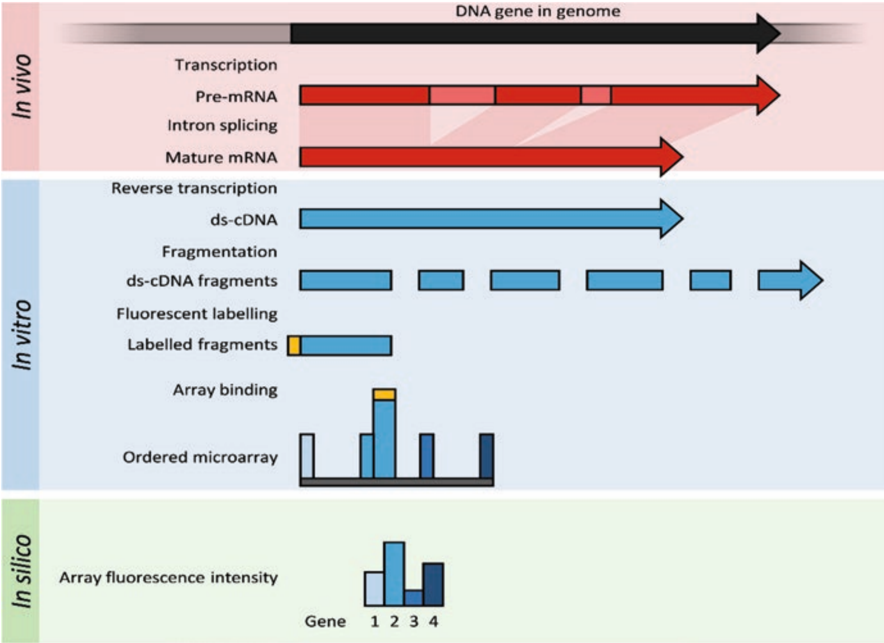

Fig. 11.3 Brief view of DNA microarrays; In the eukaryotes, after transcription genes are spliced to form mature mRNA transcripts (red). This extracted mRNA from the organism is reverse transcribed to produce stable double-stranded cDNA (ds-cDNA; blue). In microarrays, this ds-cDNA is spliced and labeled with fluorescent (orange). The labeled region bind to a composed array of complementary oligonucleotides, the intensity of fluorescent is measured that indicates the abundance of sequences (figure is taken from Lowe et al. 2017)

11.3.2.2 RNA Sequencing

There are a number of plants and animals whose genomes have been sequenced because genome sequencing is becoming feasible and cheap technology with the passage of time. RNA Sequencing provides information of gene structure, regulation, gene expression for those species which don't have their complete genome sequence (Ozsolak and Milos 2011). Generally, mRNA of an organism is extracted and converted into complementary DNA (cDNA) and fragmented through fragmentation of either DNA or RNA (Fig. 11.4). Furthermore, sequencing adapters are attached to the end of DNA fragments. These fragments are then sequenced into sequence reads using high throughput technologies for sequencing. Each molecule of short cDNA fragments will be sequenced to generate sequence reads which may have a length of 100–400 bp depends upon the sequencing technology used. Similarly, sequence reads are aligned in accordance with a reference transcript to generate a genome-wide transcription map. Consequently which can be used to annotate where that particular genes reside, their expression level and any other information regarding it. RNA sequencing has many benefits over other existing

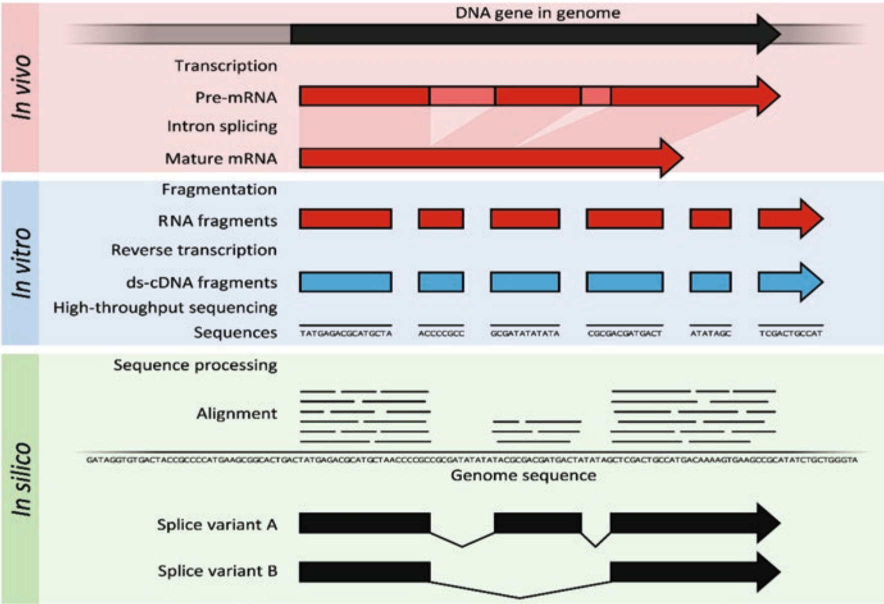

Fig. 11.4 Summary of RNA-sequencing; In the eukaryotes, after transcription genes are spliced to form mature mRNA transcripts (red). This extracted mRNA from the organism is reverse transcribed to produce stable double-stranded cDNA (ds-cDNA; blue). The short-read method is used to sequence ds-cDNA. This sequenced ds-cDNA then aligned to a reference genome to reconstruct the transcribed regions. The final data can be used for annotation (figure is taken from Lowe et al. 2017)

technologies for transcriptome analysis. First and foremost advantage which already has discussed is, it does not require any prior information of reference genome of any species, so it is attractive for non-model species. Use of high throughput sequencing technologies produce long sequence reads which help to predict the position of multiple exons and enables simultaneous quantitation and sequence analysis. Furthermore, it has the ability to distinguish allelic expression and different isoforms. Additionally, RNA Sequencing has the ability to identify the single nucleotide polymorphism (SNP) in the transcript because of high resolution.

11.3.3 Proteomics-Based Strategies

Proteomics aims to study the total proteins complement in particular organisms, organ, tissue, and cell. Much information on the physiology of the cell is determined by the gene products (proteins) on a large scale. Proteomics aims to analyze the protein expression profiles, protein-protein interaction, protein trafficking, localization, protein modification and their role in cellular processes e.g. growth, health, and disease. Furthermore, transcript data does not always correlate with proteomics data. There are 20,000–25,000 protein-encoding genes present in a cell, while almost 1,00,000 proteins are present in our all organims. This diversity is due to alternative splicing and post-translational modifications. Proteome analysis was first carried out in model plants like *Arabidopsis thaliana* and rice (Kamo et al. 1995; Komatsu et al. 2004). There are a number of advanced techniques which are being used now for proteomics analysis.

11.3.3.1 Gel-Based Proteomics Analysis

The most widely used techniques for high-throughput analysis of proteins are gel-based proteomics techniques (Chevalier 2010). Two main steps involved in gel-based proteomics, one is a separation step (mostly 2-DE) and other is the identification step (MS). In proteomics analysis 2-DE has become the most versatile tool for separation of proteins, it resolves the proteins based on molecular mass and isoelectric point (Pomastowski and Buszewski 2014). SYPRO Ruby and silver nitrate can be used to stain the separated proteins. 2-DE facilitates the characterization of hundreds of proteins in a single polyacrylamide gel, combined with advanced Mass Spectrometric (MS) techniques. This ability of 2-DE makes it more suitable for analysis of post-translational modifications (PTMs) of proteins.

A modified version of 2-DE is Difference Gel-Electrophoresis (DIGE), which was developed to control gel-to-gel variation and to enhance the reproducibility (Beckett 2012). Before separating the sample on the same gel, different fluorophores, like; CyDye2, CyDye3, and CyDye5 are used to label the protein sample at lysine residue. This technique requires the less number of gels for a single experiment, and it can detect the single protein as small as 150 pg. 2D-DIGE has limited use because of its expensive equipment and software (Meleady 2018).

11.3.3.2 Mass Spectrometry

The mass spectrometer includes a source of energy for ionization of sample, an analyzer to separate the ions, based on mass/charge ration, and a detector to detect ions. Mass spectrometry became a robust and efficient technique for proteome analysis shortly after the appearance of electrospray (ES) and marker-assisted laser desorption ionization (MALDI) which allows the ionization of large biomolecules in a precise manner (Ireland 2013). These methods were developed in the 1980s, provides a gentle ionization of large biomolecules and their entrance into the gaseous phase. Four different types of analyzers are being used; ion trap, time of flight, triple-quadrupole tandem MS, and Fourier transform ion cyclotron resonance, all of these have different aspects and selection is based on sensitivity, mass accuracy and resolution (Baral et al. 2014).

11.3.3.3 Protein Microarray

Protein microarrays are an advanced class of proteomics, commonly known as protein chips, having the ability to detect protein from the small amount of sample. These microarrays proved to be an effective tool for genome-wide analysis of DNA-protein and protein-protein interaction, as they were used in interaction analysis of *Arabidopsis* transcription-factor (Gong et al. 2008).

11.3.4 Metabolomics Concept and Strategies

Metabolomics refers to the study of a complete set of small metabolites (metabolic intermediate, signaling molecules, hormones, and other regulatory products) in the cell, tissue, and organisms (Misra et al. 2014). Metabolites are the final products of the biological system and present in small quantity compared to the mRNA and proteins. Furthermore, there are approximately 5000 metabolites are present which includes many biological molecules which show its physical and chemical complexity. Metabolomics has been used for studying plant-biotic interactions (Tenenboim and Brotman 2016). There are multiple analytical platforms for metabolomic analysis. Analytical techniques used for detection and quantification of metabolome include thin layer chromatography (TLC), high-pressure liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS), nuclear magnetic resonance (NMR), LC-NMR, direct infusion mass spectrometry (DIMS), and Fourier–transform infrared (FT-IR), etc. NMR and MS-based technologies are the most widely used techniques in metabolomics (Kim et al. 2011; Weckwerth 2010). Selection of the suitable technique mainly depends on the sensitivity, speed, and accuracy of the experiment. NMR is relatively selective and fast, while MS-based methods are good for sensitivity and selectivity but take a long time for analysis (Sumner et al. 2003).

11.3.4.1 MS-Based Techniques

Mass spectrometry (MS) coined with gas chromatography (GC-MS) and liquid chromatography (LC-MS) is most preferably used for the analysis of transcriptomics and metabolomics. The working principle for both the techniques is more likely the same except few differences for which these are preferred. GC-MS is basically used for the volatile and low molecular weight compounds and it's a hard ionization technique (Weckwerth 2003). On the other hand, LC-MS is a soft ionization technique and used for thermally unstable compounds and for those molecules which have a molecular weight in kiloDalton (kD) (Scherling et al. 2010; Weckwerth 2003). Furthermore, it has a strong application for the analysis of food pesticides and plant phenols. GC-MS is the most frequently used technique in metabolomics for identifying and quantitation of small intermediates involved in metabolic pathways like sugars, amino acids, alcohols, and organic acids. Consequently, these MS base techniques coupled with GC and LC boost the capabilities of both the techniques synergistically showing more efficacy and sensitivity (Tang et al. 2017).

11.3.4.2 Nuclear Magnetic Resonance (NMR)

In metabolomics, also called as metabonomics for NMR-based applications, NMR has been used for biochemical and phytochemical analysis (Kikuchi and Hirayama 2007). NMR spectroscopy is an unbiased, non-destructive method that requires minimal sample preparation. Sample separation is not the basis of NMR analysis, rather it provides the selection of biological sample without separation. It is also not dependent on analyte polarity, therefore no derivatization of sample is required before analysis. A strong magnetic field is applied on samples, in the result of energy absorption, nuclei from low-energy state promote to the high-energy state. Promotion of nuclei emits the radiations that produce the signals which can be recorded on the NMR spectrum (Tugizimana et al. 2013). So, all the metabolites, primary and secondary, can be viewed by NMR analysis (Kim et al. 2011).

11.3.5 Interactomics Concept and Techniques

Interactomics aims to study the whole set of interactions happen in the cell and first time coined by the team of French scientist Bernard Jacq in 1999 (Sanchez et al. 1999). It points all the interaction either these are among proteins or other molecules and consequences of these interactions. Protein-protein interaction is the center of cellular processes (Shachuan et al. 2015). This interaction may be between the same families or different families like protein, carbohydrate, lipids and nucleic acid but mostly transcriptome refers to the protein-protein interaction and protein-DNA interactions. Many techniques have been developed for the verification of these interactions. For an appropriate map of the interactome, the collaborative dataset is required from different methods. Commonly, two main experimental methods are used: one is based on biochemical methods (affinity purification, immunoprecipitation, protein array, and gel-based techniques, etc) and another one relies on genetic transcript approaches the yeast-two-hybrid screen and phage display).

11.3.5.1 Yeast-Two-Hybrid (Y2H) Technique

In Interactomics yeast-two-hybrid (Y2H) technique (Fig. 11.5) is most widely used for the determination of protein-protein interactions and protein-DNA interactions (Lopez and Mukhtar 2017). Two domains are important for the Y2H assay: (1) DNA binding domain (DBD) which is responsible for the binding of DNA, and (2)

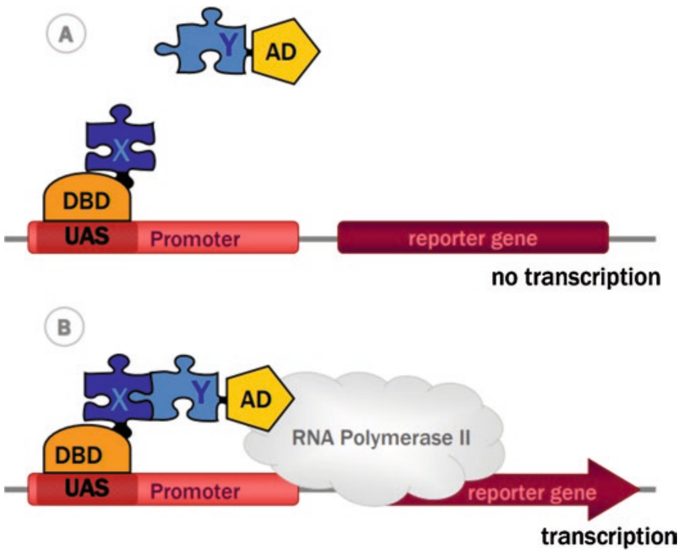

Fig. 11.5 Simple representation of yeast-two-hybrid system (**a**) One protein (X) is fused with AD and act as bait while other interacting protein (Y) is fused with DBD called prey, when they are apart from one another no transcription takes place (**b**) When they come in close proximity, transcription of the reporter gene takes place (figure is taken from Bruckner et al. 2009)

activation domain (AD) which activates the transcription of the reporter gene. This in vivo approach based on the fact that eukaryotic transcription factor has a modular structure. DBD domain and AD domain can be fragmented into two parts and when they come into close proximity they can activate the transcription of a reporter gene even though not connected. These fragments, one consist of C terminal activation domain fused with the protein of interest (Y) is known as prey and other fragment of transcription factor consist of N terminal DNA binding domain fused with another protein of interest (X) is called bait as shown in (Fig. 11.5). Selection markers are also attached with these fragments to ensure that desired fragment has been transformed into the yeast. The yeast used for this purpose is genetically engineered and in which transcription of the reporter gene leads to specific phenotype and grown on selective media. When bait and prey protein interacts and consequently DBD and AD come into close proximity activates the transcription of the reporter gene. Gal4 is a yeast transcription factor (having both DNA binding and activation domain) is most frequently used for fusion with the partner protein. Y2H is cost-effective, sensitive technique and also allows in vivo studies of protein interactions which play a key role in different cellular processes (Janik and Schlink 2017).

11.4 Applications of Omics-Based Strategies in Agriculture

Omics have proven its effectiveness through the use of many ultra-high throughput technologies which have the capability to provide detailed insights into the genome, transcriptome, proteome, metabolome, the interaction of desired proteins and their consequences. This information can be utilized to modify the crop genome or enhance its characteristics (Fig. 11.6).

11.4.1 Improved Varieties with Enhanced Yield and Nutritional Values

Omics technology has a broad range of applications and helped agriculture in many ways. Through this technology, it is easy to identify the genes of important pathways across the phyla and kingdom as protein identification, profiling and quantification of small metabolites of a biological system involved in the yield and quality improvement can be accomplished (Hall et al. 2008). This knowledge can be used to increase the expression of relative proteins and metabolites in order to gain the desired product (Struik et al. 2007). Improvement in the nutritional quality of plants has been possible through the essential knowledge of plant metabolism and interaction between thousands of metabolic pathways. Protein deficiency causes a severe type of malnutrition, as according to the World Health Organization every fourth

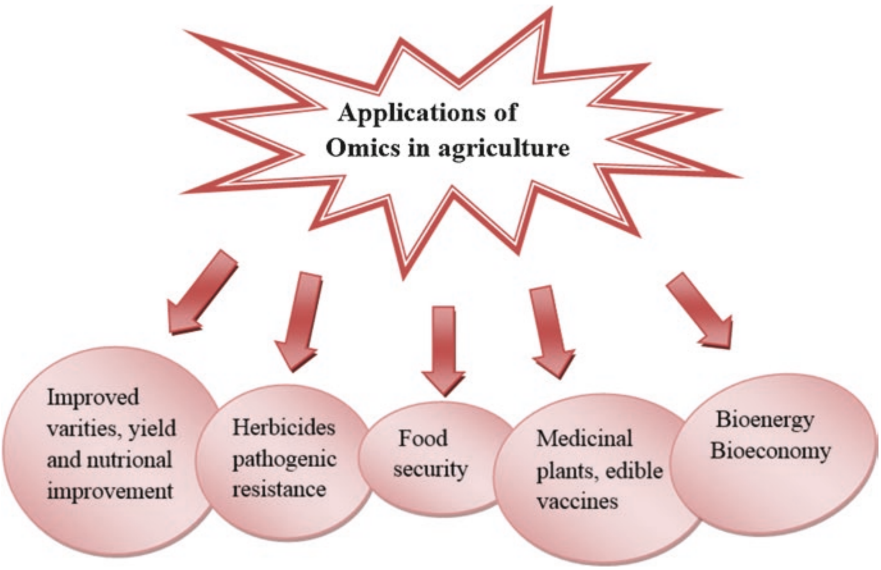

Fig. 11.6 Omics applications in agriculture

child suffers from protein deficiency (Organization 2006). This can also be cure by enhancing and balancing the protein content in the cereals and legumes for example transgenic canola and soybean have been produced with high levels of lysine (Falco et al. 1995). High lysine maize produced by transferring *dapA* gene from *corynebacterium glutamicum* which codes for the dihydrodipicolinate synthase enzyme that is insensitive to the lysine inhibition (Brinch-Pedersen et al. 2000). Moreover, artificial protein has been produced having more lysine cysteine and methionine content in stable form and resistant to protease treatment. Micronutrient deficiency which is also a severe threat and effects about half population of the whole world (Nutrition 2004). Vitamins and minerals are also limited in diet. Many attempts has been done to improve the level of vitamin E in soybean canola wheat (Newell-McGloughlin 2008). Rice is the staple food of about half of the world population. Golden rice which is the name given to genetically modified rice, produces beta carotene which is responsible to produce vitamin A (Ye et al. 2000). β-Carotene produces in the endosperm using different genetic engineering approaches and golden name is due to the yellow color of rice (Al-Babili and Beyer 2005). Golden rice have a potential to eradicate the vitamin A deficiency, help in cellular differentiation growth and boost up immune system (Sommer 1982; Ye et al. 2000). Iron deficiency which is associated with low hemoglobin level is also increasing day by day in children and adults. Using grain from genetically engineered rice can cope with this deficiency (Lucca et al. 2002).

11.4.2 Development of Herbicides and Pathogenic Resistant Varieties

Weeds are a major source of crops diseases and decline in the yield of crop alternatively which leads to the low quality of crops along with their quantity (Oerke 2005). In 1940, 2-methyl-4-chlorophenoyacetic acid (MCPA) and 2,4-dichorophenoxyacetic acid (2, 4-D) were used for the first time as synthetic herbicides to control weeds as they were very effective and selective phenoxy herbicides. Since then a number of herbicides belonging to the different chemical group have been discovered and applied on vast varieties of crops for weed control (Mithila et al. 2011; Reddy and Nandula 2012). Herbicides provide an efficient way to control weeds in an economically acceptable manner and increase productivity. Extensive and continued use of weed killers have developed resistance in pest against these herbicides which is a serious condition (Van Emon 2016). Various herbicide-resistant crops like soybean and canola have engineered in the United States using Omics based technologies (Van Emon 2016). For the first time in 1996, cotton variety with the added function of insect-resistant, by using biotechnological approaches, was commercialized in the USA. That was named Bt cotton as a gene from bacterium *Bacillius thuringensis (Bt)* was transferred to cotton. This gene is responsible to make a protein which has lepidopteron-active insecticidal function (Head and Dennehy 2010). This protein has the potential to provide protection from corn earworm, European corn borer, corn rootworm and cotton bollworm throughout the life span of the plant (Van Emon 2016). Omics technologies play a key role to study the evolution of herbicide and insecticide resistant in plants. All the biochemical and metabolic pathways responsible for resistant can be studied.

11.4.3 Global Food Security

Food safety and food quality are two important components to maintain the sustainability of safe economical food supply and are critical for improving food security worldwide. According to reports, there is approximately 3.6 million bacterial foodborne illness in the United States and 10.3 million across the globe (Havelaar et al. 2015; Scallan et al. 2011). The use of high throughput omics technologies facilitates the broad range of sampling and detection of a large range of pathogens and foodborne illness. Utilization of these techniques to develop better screening tools for pathogens can help to improve the food quality and food safety (Forbes et al. 2017). Another significant transformation in the field of microbiology is the whole-genome sequencing of foodborne bacterial pathogens which is an alternative to subtyping method (Deng et al. 2016). Protein makes up the large fraction of many food products. Nutritional and rheological properties of milk, cereal, and meat-derived products are determined by the protein fraction of that product. MS-based technologies give a way to examine the protein profile and give an estimation of any adulteration present in that food product (Mamone et al. 2009). Molecular-based techniques have proven themselves as an efficient way to detect food safety and integrity. They use specific DNA sequence to find out the originality of raw ingredients used in the making and adulteration of foods (Burns et al. 2016).

11.4.4 Production of Medicinal Plants and Edible Vaccines

Cost of all the therapies required for many diseases is also very high for example inulin like growth factor (IGF-1) cost $30,000 per mg while interferon therapy cost $ 26,000 for viral infection (Cowley 2002). Trained personnel, storage temperature disposal of syringes and knowledge of administration dosage also hurdle the use of injectable vaccines (Richter and Kipp 2000). Due to these and many more reason plants are being used for therapeutic purpose and edible vaccines at an affordable cost. Plants derived product are less likely to affect by pathogenic microorganism (Giddings et al. 2000). Growth hormone was the first human protein successfully expressed in *Agrobacterium tumefacien* (Barta et al. 1986; Schillberg et al. 2003). Expression of antibodies in tobacco also showed the ability of plants to produce the human therapeutic protein (Hiatt et al. 1989). Genetically modified maize, alfalfa, soybean and tobacco also have the potential to produce therapeutic protein and reduce the cost of the process by 90% (Larrick and Thomas 2001). Transgenic tomatoes have been used to manufacture anti-malarial edible vaccine. They immunize the individual against 2–3 antigens and against the each stage of the multistage parasite. Tomatoes having different shapes, size and color carrying different antigens, make them easily identifiable (Chowdhury and Bagasra 2007). Likewise, cholera toxin subunit B (*CTB*) gene has been successfully expressed in tobacco (Hein et al. 1996; Wang et al. 2001) and tomato plants (Arakawa et al. 1997). Tomato plants expressed *CTB* gene in their leaves and fruits consequently which suggest the use of tomato based vaccine against cholera (Jani et al. 2002). Banana, potatoes, tomatoes are being used to produce edible vaccines because of their appealing nature. Desired gene responsible to produce intended antigen can be transferred to the edible tissues of plant to produce encoded proteins in their fruit (Mason et al. 2002). These oral vaccines served many advantages over injectable vaccines which includes easy to use, store, administer, cost efficient and readily acceptable (Lal et al. 2007). Furthermore, oral vaccines activate mucosal antibodies which serve as first line of defense against infections (Richter and Kipp 2000). Banana and tomatoes have the tendency to manufacture vaccines in their fruits to diphtheria, measles, tetanus, tuberculosis, polio, pertussis and hepatitis B (Ahmad et al. 2012).

11.4.5 Bioenergy and Bio-economy

Bioenergy which is also defined as energy that comes from biological sources which are renewable having never ending sources (Paz 2013). Bioeconomy which involves the utilization of these natural/biological sources to manufacture different bio based products. It provides an effective way to cope with the food insecurity, resource scarcity, environmental risk and provide eco-friendly and sustainable bio based products in all sectors like food, feed, paper, fisheries and agriculture (Scarlat et al. 2015). In south Asia approximately 25% of primary energy comes from biomass which is a replenishable source (Mukhopadhyay et al. 2018). Along with the production of bio based products, bioeconomy also pave the way to eradicate world global warming which will help the countries to reduce the CO2 level (Priefer et al. 2017). Use of biogenic source provides less dependence on fossil fuel which are non-renewable and expensive resource (Staffas et al. 2013; Vandermeulen et al. 2012). Much strain on the use of fossil fuel for energy production can become threatening condition in the future (Barceló et al. 2019). Furthermore, genomics and synthetic biology has the much potential for the production of microbial factories which will help in the production of chemical compounds for the industry. Synthetic biology is producing fuels by bringing in use lignocellulose. Lignocellulose from non-food crops, food wastes and agriculture also serve as efficient energy source for bioenergy and alternatively benefit bioeconomy (Jiménez-Sánchez and Philp 2015).

11.5 Current Challenges in the Way of Transgenic Crops and Future Insights of OMICS

11.5.1 Current Challenges

There is always two sides of a story, same is the case with transgenic crops and their release on the global level. There are some concerns associated with them, some are scientific and other are ethical. Scientist just deal with what we need and what can solve the problem in an easiest way (Sheldon et al. 2006). Other is the ethical side which concerns with what we ought to do and the possible outcomes of this modification. Their hazards on human, animal, environment and to some extent on the economic level are concerned (Weil 1996). On economic level cost of genetically modified seeds is also very high, it will deprive the poor farmers to access the market and purchase these seeds to compete with the modern agriculture (Bradford et al. 2005). Awareness of the transgenic crop also hurdle the way to adapt this technology as no one wants to experience a genetically modified food and people just scare of listening to its name (Godfrey 2000). In this whole scenario, there is an urge of complete risk assessment of genetically modified crops before their movement around the globe and efficient regulatory framework is required which will especially check the biosafety and other hazard associated with the GM crops (Tsaftaris et al. 2000). Use of those gene for which most people are sensitive must be prohibited.

11.5.2 Future Insights

As described earlier, world population would be doubled by the year 2050. Many challenges to feed the hunger of such a huge population will arise. Moreover, natural resources are decreasing for agricultural use, climate conditions, water salinity, drought, water logging, and many more issues make this problem more alarming (Tilman et al. 2001). According to an estimate many countries across the globe will experience water shortage by the year 2025 (Ruttan 2005). Genetic improvements in crop plants are needed to improve the current capabilities of crop and make them efficient in productivity, quality, food safety and tolerant to many stresses in less land (Setia and Setia 2008). This has led the scientist to explore the power of OMICS based strategies to introduce the desired modifications in the plants (Setia and Setia 2008). These technologies encompass many unbiased factors related to yield and growth of crops, insights into the complex traits, its metabolism and genes which are involved in the response mechanism to the various kind of stresses either biotic or abiotic (Raikhel 2005; Struik et al. 2007; Vassilev et al. 2005). Moreover, detailed analysis of biological system, gene sequencing, annotation, characterization and expression analysis at transcriptome, proteome and metabolome level contributed a lot information on the physiology of plant and its behavior. Moreover, it also helped in the identification of agronomically important genes at the biochemical and molecular level (Campbell and Heyer 2006; Setia and Setia 2008). Next generation sequencing also played its role in the revolution of genomics, through which different genes underlying different processes like fruit ripening (Gapper et al. 2013; Klee and Giovannoni 2011; Seymour et al. 2013) and epigenetic factors can be estimated in a short span of time. Different Omics technologies have been used to introduce many advantageous alterations in the plant genome. These alterations show their functions by boosting or suppressing existing genome of the crop plant. Crops like rice, cotton, canola, cassava, squash, potato, maize, soybean, groundnut, papaya, oil seeds and many other vegetables and fruits have been modified through various gene transfer methods (Asif et al. 2011; Chakraborty et al. 2010; Hutchison et al. 2010; Llorente et al. 2010; Mendoza et al. 2008; Motoyama et al. 2010). Due to the ongoing advancement and globalization of transgenic crops, this topic is getting heated among states. No doubt transgenic crops are the best option to cope with the future food scarcity and water shortage probably we have to face due to the exponentially increasing population in the coming years (Bradford et al. 2005). Furthermore, having information about the whole biochemical pathway associated with desired traits we will be able to transfer the complete pathways from one specie to the other (Conner and Jacobs 1999; Pandey et al. 2010).

Many transgenic plants has been produced using modern technologies (Omics based) for different required characteristics. Few of them are listed in (Table 11.3).

11.6 Conclusion

Nearly 70% of people living in rural and developing countries are food insecure, suffering from poverty and malnutrition. According to estimates world's population would be doubled in next very few years. Conventional breeding approaches which are based on phenotypic characteristics to select improved and better genotypes in the next generation. But there are many factors which hamper this process like low heritability due to direct selection and there is no way to check it in the early stages of breeding. Furthermore, conventional breeding is mostly used for qualitative traits not quantitative or complex traits that's why polygenic effects and genotype-environment interactions also slows down this process. As discussed earlier, conventional breeding approaches need effective population size to be applied. There is no way to evaluate the efficiency of selection and recombination events (which may or may not be successful) in between the process. Most of all conventional breeding schemes are much time consuming and breeders have to wait a lot for results. While in contrast to this, Omics have many advantages over traditional breeding. There is no restriction to apply this technology for qualitative or quantitative traits and marker development has also allowed selecting particular population for analysis. Having all the information on the physiology of plants, knowing all the genes, proteins and metabolites which are directly involve in the crop improvement provides an ease to breeders. It can be a way to have maximum from minimum by integrating

Table 11.3 Production of transgenic plants with improved traits using various modern technologies (Ashraf and Akram 2009)

Gene studied	Source	Transgenic plant	Trait modified	References
DREB (dehydration responsive element binding protein) gene, designated as *BjDREB1B*	*Brassica juncea* L.	Tobacco	Salinity and drought tolerance due to the increased content of proline.	Cong et al. (2008)
Trehalose-6-phosphate synthase (TPS1)	*Saccharomyces cerevisiae*	Tomato	Increased starch content, thick shoots, dark green leaves, tolerance to abiotic stress.	Cortina and Culianez-Macia (2005)
Plasma membrane Na+/H+ encoding SOS1 gene	Wild type *Arabidopsis thaliana* L.	*Arabidopsis thaliana* L.	Germination rate, plant growth, chlorophyll and protein content increased.	Shi et al. (2003)
Vacuolar Na+/H+ encoding *BnNHX1 gene*	*Brassica napus*	Tobacco	Yield, flowering rate, and plant growth increased.	Wang et al. (2004)
Mannitol 1-phosphate dehydrogenase (*mtlD) c*	*E.coli*	*Arabidopsis thaliana* L.	Mannitol, fructose, proline, sucrose content were improved.	Thomas et al. (1995)
Bacterial *bet*A gene	*E.coli*	Cabbage	Improved salinity tolerance, water maintenance in salinity conditions, and growth rate.	Bhattacharya et al. (2004)
Δ^1-pyrroline-5-carboxylate synthetase (P5CSF129A)	*V. aconitifolia*	Tobacco	Increased seedling growth, proline content of transgenic pant, reduced oxidative stress.	Hong et al. (2000)

Omics technologies at crop level. Omics seems an only option to cope with current food demands of exponentially increasing population. In this entire scenario, we need more focused and oriented work on the modern technologies to grow more efficient crops and to eradicate the food challenges that most countries are facing or may have to face in future.

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Chapter 12
Development and Applications of Transplastomic Plants; A Way Towards Eco-Friendly Agriculture

Md Jakir Hossain and Allah Bakhsh

Abstract With distribution of genetic materials and advance molecular characteristics, the chloroplast is prokaryotic compartments within the eukaryotic plants that have turned into a crucial source for the genetic engineering and transplastomic plants are becoming more popular means of agricultural development with elevated crop yield. To address global agricultural problems, genetic modification of crop plants is a rapid and promising solution to adapt the environment-friendly and well-controlled farming system. The transplastomic plant with high accumulation of foreign proteins (up to 45–46% TSP) and stable transgene expression with gene containment can be a unique choice for the agricultural innovation of coming centuries. Although the transplastomic plants still facing encumber to ensure the full potential exploitation and expansion as an economical means, the removal of hardness and obstacles of this technology and commercialization can contribute for the sustainable development of future agriculture. In this book chapter, we intend to recapitulate the up to date development and achievement of transplastomic plant including gene transfer procedures in plastid genomes, regulable expression of plastid transgenes, plant trait improvement by foreign gene expression, biopharmaceuticals production, engineering of metabolic pathways in plant, study of transformation mediated RNA editing technologies, bio-safety issues and public concerns on transplastomic plants and overall beneficial aspects. We believe that the utilization of transplastomic plants will ensure an eco-friendly approach in agriculture with minimized hazards and public concerns.

Keywords Chloroplast transformation · Gene containment · Sustainable agriculture · Environmental friendly

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_12

12.1 Introduction

Besides the nuclear genome of algae and plant, plastid containing chlorophyll and other pigments with their own genome or plastosome conducting photosynthesis is known as chloroplast that is executed from the bacteria which are free living in nature and possess primitive type of gene expression apparatus (Verhounig et al. 2010). Having most ancestral genes and less prone to genetic recombination characteristics, Chloroplast serves as an extraordinary tool for evolutionary and phylogenetic studies that reveals the carbon sequestration, starch production, amino acids and fatty acids synthesis with pigments and it is vital scene metabolism of sulfur and nitrogen (Verma and Daniell 2007). Chloroplast transformations have become winsome substitute to nuclear gene transformation due to having several conveniences include: elevated level of protein in transgene, the probability of multiple proteins expression from polycistronic MRAs and stifle of genes because of the lacking of pollen dispatch mechanism (Maliga and Tungsuchat-Huang 2014). In spite of prokaryotic past, plastid gene expression has various regulatory mechanisms found in bacteria and in most angiospermic plant it is maternally inherited where one thousand to ten thousand copies of genome is present in every cell with the diameter between ~120–150 kb (107 kb in Cathaya argyrophylla and 218 kb in Pelargonium) (Hagemann 2004). Every single plant contains about 300 plastid with 1000–10,000 copies that that is quite dissimilar than the nuclear DNA where the genome is consist of double stranded circular DNA through the formation of complete genome structure and common structural pattern in almost all higher plant species. As structural components it contains large (LSC) and small (SSC) single copy with duplication of large region (~25 kb) named IRs that is situated in an inverted orientation (Vesteg et al. 2018). Fig. 12.1 will represent all structural information of chloroplast genome.

As plastid genome has high ploidy number and nature of its protein compartment allow the increased levels of foreign protein manifestation that ranges from 5 (five)

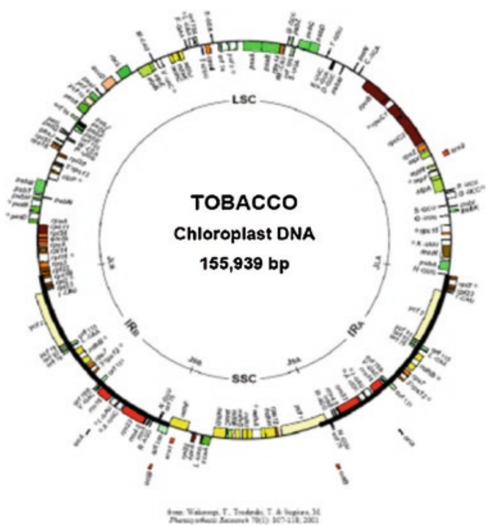

Fig. 12.1 Tobacco plastid genome (*Nicotiana tabacum*)

to 40 (forty) % of TSP (total soluble protein) (Hagemann 2004) and in tobacco, it was found up to 70% of TSP (Wang et al. 2009). Moreover, high accumulation of nuclear encoded proteins can be found in chloroplast genome although the ploidy level is not as high as chloroplast encoded proteins. As a result, by the dint of recent biotechnological development chloroplast is regarding as an ideal host for conferring the traits of agronomic important and the production of biopharmaceuticals, biomaterials and industrial enzymes has been performed (Harris and Ingram 1991). By the grace of recent high – throughput genome sequencing, more than 230 photosynthetic organisms including 130 higher plants complete genome has been sequenced where 80% angiospermic plant plastid are usually maternally inherited. To avail the various applications, via chloroplast genome more than 120 (100–250) genes from several sources has been well integrated and expressed. These includes: highly insect, bacteria, fungus, viral abiotic stress resistance crop development, phytoremediation of toxic metals, metabolic engineering, production of many vaccine antigens, cytoplasmic male sterility, industrial enzymes and biofuels and Biopharmaceuticals (Verhounig et al. 2010).

12.2 Historical Milestones of Transplastomic Plants

First successful genetic engineering of chloroplast was developed in 1980 and then generation of primary transgenic plant was possible by introducing an isolated intact chloroplast and early investigation of chloroplast transformation emphasized on the development of chloroplast system in vascular plants that was able to introduce an effective and durable protein synthesis and expression of foreign genes. (Daniell and McFadden 1987). As a primitive attempt in 1988, Particle bombardment method of DNA delivery was used to introduce cloned DNA into the genome and durable transformation of chloroplast was performed in a primitive algal species *Chlamydomonas reinhardtii*. According to the report of Svab and Maliga 1993, chloroplast genome engineering in Tobacco (among the higher plants) was initiated in 1990. Recently, engineering of tobacco plastid genome has been done to express E7 HPV protein that can be regard as an attractive alternative candidate for the production of anti cancer vaccine and similarly a plastid transformation protocol of elite rapeseed (*Brassica napus* L.) cultivar have been developed. Table 12.1 will summarize the chronological historical progress of chloroplast genome engineering.

More recently, brinjal (*Solanum melangona* L.) plastid has been transformed with expression vector (pPRV111A) harboring aadA gene that encodes aminoglycoside 300-adenyltransferase. Up to date, in cases of many higher plant like Arabidopsis thaliana, Potato, Tomato, petunia, lettuce, soybean, cotton, carrot, rice, poplar, tobacco, mulberry and eggplant plastid transformation technology has been extended (Okumura et al. 2006).

After the in invention of particle bombardment as a device for the plant chloroplast transformation, direct gene incorporation rather than the use of isolated plastid was enabled (Daniell 1993). In dicot plant, Chloroplast transformation was

Table 12.1 Historical development of Transplastomic plants

Species	Years	Methods of DNA delivery	Process of selection	References
Chlamydomonas reinhardtii (first durable plastid transformation)	1988	Particle Bombardment	Photosynthetic Competence	Boynton et al. (1988)
Nicotiana tabacum (first durable plastid transformation)	1990	Particle Bombardment	Spectinomycin	Svab and Maliga (2007)
Nicotiana tabacum (first elevated level foreign protein expression in)	1993	PEG	Kanamycin and Spectinomycin	Golds et al. (1993)
New agronomic traits: *Bacillus thuringiensis*, Marker gene elimination: Co-transformation	1995	Particle Bombardment	Spectinomycin	McBride et al. (1995) and Carrer et al. (1993)
Arabidopsis thaliana (first stable plastid transformation)	1998	Particle Bombardment	Spectinomycin	Sikdat et al. (1998)
Solanum tuberosum and *Oryza sativa* (first stable plastid transformation)	1999	Particle Bombardment	Spectinomycin	Sidorov et al. (1999) and Khan and Maliga (1999)
Nicotiana tabacum (first Human Protein expression)	2000	Particle Bombardment	Spectinomycin	Staub et al. (2000)
First foreign protein in *Lycopersicon esculentum* (Tomato) Marker gene elimination: CRE-lox, New agronomic traits: Glyphosate tolerance and PPT resistance	2001	Particle Bombardment	Spectinomycin	Ruf et al. (2001)
Foot and mouth disease virus VP1 protein expression, first stable plastid transformation in Brassicaceae and Phytoremediation: Murkery	2003	Particle Bombardment	Spectinomycin	Ruiz and Daniell (2005)
Gossypium hirsutum (Cotton) PHB polymer expression in *Linum usitatissimum usitatissimum L.*	2004	Particle Bombardment	Spectinomycin, Aph-A6 and nptII	Kumar et al. (2004b)
Stable Plastid transformation in *Populus alba*	2006	Particle Bombardment	Spectinomycin	Okumura et al. (2006)
Cabbage-*Brassica oleracea var. capitata*	2007	Particle Bombardment	Streptomycin and Spectinomycin	Liu et al. (2007)
Sugar beet (*Beta vulgaris*)	2009	Particle Bombardment	Spectinomycin	De Marchis et al. (2009)
Brinjal (*Beta vulgaris*)	2010	Particle Bombardment	Streptomycin and Spectinomycin	Singh et al. (2010)
Alfaalfa (*Medicago sativa*)	2011	Particle Bombardment	Spectinomycin	Wei et al. (2011)
Potato (*Solanum tuberosum*)	2012	Particle Bombardment	Streptomycin and Spectinomycin	Segretin et al. (2012)
Nicotiana tabacum-Tobacco	2014	Particle Bombardment	Cytokinin free	Dunne et al. (2014)

Table 12.2 Transformation of chloroplast has been achieved in the following crop plants

Crops	Proteins or Traits	Genes used	References
Potato (*Solanum tuberosum*)	GFP and Amino glycoside adenyl transferase	gfp, aadA	Sidorov et al. (1999)
Tobacco (*Nicotiana tabacum*)	Amino glycoside adenyl transferase	aadA	Svab et al.(1990)
Tomato (*Lycopersicon esculentum*)	Amino glycoside adenyl transferase	aadA	Ruf et al. (2001)
Rice (*Oryza sativa*)	GFP and Amino glycoside adenyl transferase	gfp, aadA	Lee et al. (2006)
Petunia (*Petunia spp.*)	Amino glycoside adenyl transferase, β-Glucuronidase	aadA, uidA	Zubko et al. (2004)
Oilseed rape (*Brassica napus*)	Amino glycoside adenyl transferase, Crystal protein insecticidal	cry1Aa10, aadA	Hou et al. (2003)
Cotton (*Gossypium hirsutum*)	Neomycin phosphotransferase II, Amino glycoside adenyl transferase	aphA6, nptII	Kumar et al. (2004b)
Arabidopsis thaliana	Amino glycoside adenyl transferase	aadA	Sikdat et al. (1998)
Carrot (*Daucus carota*)	Betaine aldehyde, Amino glycoside adenyl transferase	aadA, badh	Kumar et al. (2004a)
Lettuce (*Lactuca sativa*)	GFP, Amino glycoside adenyl transferase	aadA, gfp	Lelivelt et al. (2005)
Soybean (*Glysin max*)	Amino glycoside adenyl transferase	aadA	Dufourmantel et al. (2007)
Eggplant (*Solanum melongena*)	Amino glycoside adenylyl transferase	aadA	Singh et al. (2010)

corroborated through self replicating vectors of chloroplast and in cases of monocot plant transient expression was used but using the gene gun, stable integration of selectable marker gene in tobacco and *Chlamydomonas* plastid genome was done (Goldschmidt-Clermont et al. 1991). Nowadays, the genes that only contain valuable agronomical traits is being introduced through the genetic engineering of chloroplast, for instance, the chloroplast genome integrated with cry gene produced plants that contained insecticidal property to Bt (*bacillus thuringiensis*) sensitive (McBride et al. 1995) and broadly resistant to insects (Kota et al. 1999). To ensure tolerance against bacterial and fungal diseases, drought or herbicides chloroplast also been engineered (Kittiwongwattana et al. 2007). Transgenes, up to date engineered through chloroplast genome are listed in Table 12.2.

12.3 Chloroplast Transformation Procedures

For the successful chloroplast transformation multiple steps are involved. Heterologous or species specific vectors for chloroplast transformation can be developed by flanking the foreign genes and inserting them at scheduled proper site in the plastosome through homolographic projection (homologous recombination). After the incorporation of foreign proteins into the plastosome, primarily only a few copies of the plastid genome were transformed and turned into heteroplasmic state. Then through the sub-culture in in vitro condition under the selection all copies of plastosome of bombarded explants reach to the homoplasmic state.

Entire chloroplast transformation technology involves the following steps:

(a) An expression vector that is specific to chloroplast
(b) A robust DNA delivery method to chloroplast through a double membrane.
(c) System of transplastome selection need to be efficient

Commonly, to achieve the successful transformation of chloroplast three major conditions have to be assured:

(a) A strong DNA delivery method
(b) An effective homologous type of recombination procedure in plastid, and
(c) Existence of high and efficient regeneration and selection manual for transplastomic cells.

For the proficient transformation, complete homology of plastid DNA flanking sequence is required.

12.4 Vector Design for Development of Transplastomic Plant

12.4.1 Selectable Marker Gene

At the first attempt of chloroplast transformation technology, 16S rRNA (rrn16) plastid was utilized as selection marker and transgenic lines were selected by spectinomycin that showed less transformation efficacy. Dominant markers confer high transformation efficacy, as for example: aadA (aminoglycoside 3′ adenylyl transferase) ensure resistance to both streptomycin and spectinomycin by the antibiotics inactivation (Kittiwongwattana et al. 2007). It was found that if the transformation is carried out having aadA gene it increase the plastid transformants recovery in remarkable rate and in such a manner that denotes a single transplastomic line per bombarded leaf (Svab and Maliga 1993). At initial stage of selection and regeneration process to represent as visual marker GFP (Green fluorescent Protein) was applied for the transformed plastid. As plastid DNA contains many copies, in order to avail uniform transformation efficacy of genome copies selectable marker genes are very important in enrichment process that leads the gradual selection of plastids those show non-transformed nature on the selective medium (McBride et al. 1995). For the plastid transformation of tobacco, another selectable marker *nptII* was also used that resulted low transformation efficacy and it shows approximately one transplastomic line per twenty five (25) bombarded explants (Carrer et al. 1993), other trial was conducted with highly expressed *neo* gene that revealed a remarkable and dramatic transformation efficacy where Twenty five (25) leaves with the vector showed thirty five clones having resistant property to kanamycin (Kuroda and Maliga 2001). *bar* gene from bacteria encoding PAT (Phosphinothricin acetyltransferase) showed fewer efficacies as marker gene (Lutz et al. 2001) and betaine aldehyde dehydrogenase (BADH), another marker gene that was capable to confer resistance to betaine aldehyde. In tobacco, betaine aldehyde selection with spectinomycin showed 25-fold higher chloroplast transformation efficacies (Daniell et al. 2001). Transgenic cottons manifesting BADH may be produce with the existence of elevated concentration (about 400 mmol/L) of NaCl (Kumar et al. 2004b).

12.4.2 Insertion Sites

Foreign DNA insertion into the plastid intergenic regions had been performed at 16 sites and major 3 of them are: *trnV-3′rps12, trnI-trnA* and *trnfM-trnG* that are commonly used. The *trnV-3′rps12* and *trnI-trnA* insertion sites are situated in the 25 kb IR region (inverted repeat) of ptDNA and thus a gene that will be incorporated into these insertion sites would possesses the potentiality to make two copies rapidly in the IR region. In tobacco, most commonly used vector is the *trnV-3'rps12* that confer high level expression of proteins (Maliga 2003) and were possessed with the signals of gene excision (Lutz et al. 2006). PSBL – CTV2 is the targeting insertion vector for the *trnI-trnA* IR that was first developed and used for several proteins (Daniell et al. 2005) at Daniells laboratory (Daniell et al. 1998). Later on, several laboratories started to practice the insertion of transgenes between *trnI and trn A* genes in many plants (Daniell et al. 1998). Within the ptDNA single copy region (Large) consider as the location for *trnfM-trnG* insertion site and the genes that has been inserted between *trnfM and trnG* site should contain only 1 copy in every ptDNA. From the promoter upstream of *rrn16* operon was transcribed and these 2 TRNAs are localized between the subunit genes of RNA named large (*rrn23*) and small (*rrn16*) respectively.

12.4.3 Regulatory Sequences

Gene expression level in transplastomic plant eminently ascertained by the promoters and the elements of 5′-UTR (Gruissem and Tonkyn 1993) and with the binding sites of ribosomes (RBS) suitable 5′-UTRs are vital requirements for the expression vectors of plastid. To avail the extensive accumulation of protein from the expression of transgene, strong promoter is first prerequisition that ensure elevated level of mRNA and most laboratories use the strong rRNA operon (*rrn*) of plastid promoter (*prrn*). Sequences of 5′-UTR and 3′-UTR flanking the transgenes ensure the transgenic mRNA durability and accumulation of protein from the transgene rely on the inserted upstream of 5′-UTR that is the part of the open reading frame and it encode the traits of interest. Based on the choice of translational control signals, accumulation of protein from *prrn* promoter may differ around 10,000-fold and up to date, 5′-UTR and 3′-UTR regard as psbA/TpsbA that are commonly being used (Kittiwongwattana et al. 2007).

12.5 Methods Used in Gene Delivery into Plastids

In order to produce the foreign protein of interest, Plastid transformation intertwine the targeting of foreign genes into the double stranded circular DNA of plastid genome instead of DNA of chromosomal origin.Before achieving the homoplasmic condition all copies of plastid DNA need to have a uniform genetic structure. Although, delivery of genes into the plastosome was primarily conducted by *Agrobacterium* mediated transformation but presently both biolistic and PEG mediated treatment of protoplasts are favourite choices of scientist around the world. Entire processes of transplastomic plant development have been presented on Fig. 12.2.

12.5.1 Plastid Transformation Through Agrobacterium Mediated Method

Agrobacterium (gram-negative soil bacterium with crown gall tumors symptomology) is a prominent tool of gene transformation technology to incorporate the foreign genes of interest into plant cells and consequently transfers Ti plasmid part to

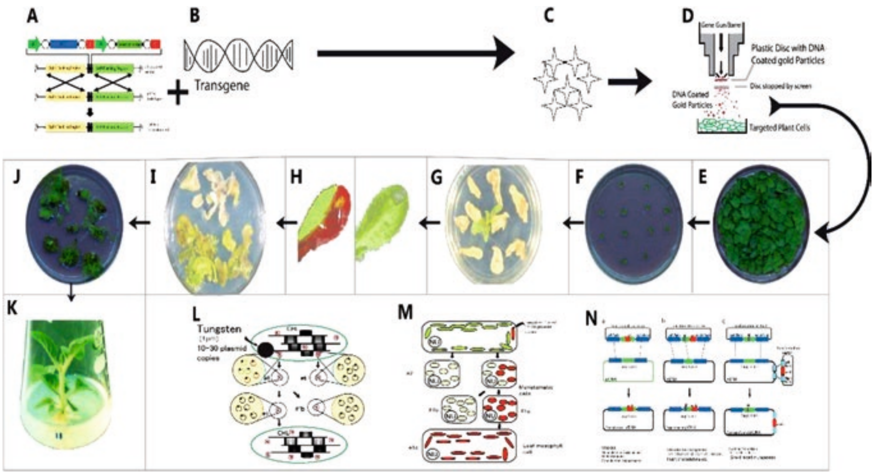

Fig. 12.2 Diagrammatic Presentation of whole Chloroplast Transformation procedure. (Adapted and drawn from several online sources)

the plant cells and integrates into the plant nuclear genome. Researchers over the years have been able to re-engineer this phenomenon by removing the gall inducing genes from the bacterium and replaced most of the T-DNA region with genetic sequences which are of interest to the scientists. Agrobacterium Ti-plasmid-mediated DNA transformation is widely used for nuclear transformation where selections for transformed plant cells confide on nuclear-expressed genes and not on chloroplasts. Although the findings from previous experiment suggested that the signals of transcription initiation inlaid in gene expression of chloroplasts are quite dissimilar from those required for nuclear gene expression. The first evidence of the utility of *Agrobacterium* Ti-plasmid vectors to introduce genes in chloroplasts was narrated by Sidorov et al. 1999 and Ohnuma et al. 2008. However, these technique remains unpopular compared to other plastid transformation methods, agroinfiltration is multipurpose and the usage with any vectors as long as it can simulate into natural engineer A. tumefaciens and trigger the T-DNA incorporation process through the virulent types of genes on chromosomes or/and another plasmid. pBIN19 or pCAMBIA is the most primitive vectors used for agroinfiltration that was driven by nos (nopaline synthase) or CaMV 35S promoters (Cauliflower Mosaic Virus) (CaMV35S). While these transcriptional vectors are not as strong as later advanced plant virus-based vectors having wide-ranging host, and can be useful in almost all plant species. These are the vectors that established the dominance of transient type of expression in response to the RP and speed yield compared to the conventional type expression of protein in transgenic lines (Verma and Daniell 2007; Krichevsky et al. 2010).

12.5.2 Gene Gun or Particle Bombardment

Particle bombardment based on a simple principle that involves the acceleration of the microprojectiles (DNA coated with gold or tungsten particles) directly into the intact tissues or cells where high speed is required and that could either are gunpowder model or PDS-1000/He™ device. In the gunpowder, DNA-coated tungsten powder is place in a small aqueous suspension at the front end of a bullet-like plastic macroprojectile.The gunpowder charge is used to accelerate microprojectiles and the macroprojectiles are extruded through a small orifice. The PDS-1000/He™ device is to initiate a microcarrier which is driven by a spurt of helium gas, upon which millions of DNA-coated microcarriers have been dried. Several improvements have been occurred in the nature of shooting of DNA on macroprojectiles with high-density into cells since 80's when first successful delivery of DNA into the plant was reported. There have been several modifications of this technique to reduce target tissue samples destruction, minimize cell damage and maximize delivery efficiency. Hedtke et al. 2002 presented an optimized method of particle gun mediated bombarding named Bio-Rad PDS-1000/He to carry gold particles coated with a target gene with selectable marker gene bar having 650 psi rupture pressure to transform the wheat immature embryos. The benefits of this technique include wide range of application to transform monocotyledons, dicotyledons, and other recalcitrant plant species. The operational procedure of this technique is easy and required a small amount of plasmid DNA and eliminates false positive results. Liere et al. 2011 reported that Particle bombardment has been employed in plastid transformation and a reproducible plastid transformation system using two diverse plastid vectors those are specific to tobacco, these are: pMON30125 (Prrn/GFP/Trps16: PpsbA/aadA/TpsbA) and pZS197 (Prrn/aadA/TpsbA).

Here we are recapitulating (Table 12.3) in brief the species those chloroplast genomes have been studied well especially its transformation methods, selection processes and expressed genes in their genomes.

12.5.3 PEG (Polyethylene Glycol) Mediated DNA Transfer

DNA transfer through Polyethylene Glycol (PEG) requires protoplasts extraction and then the Protoplasts are needed to treat with various ion containing solution together with polyethylene glycol (PEG) and DNA. In this process, the plasma membrane allows the DNA to implant and progress into the cytoplasm. The vectors design with homologous sequences to a definite target portion of the plastid genome then integrated to the target plastid genome. Antibiotics are employed for homoplastomic cells selection from segregating transformed plastome copies. Hemagglutinin (HA)-tagged b-tubulin has been transiently expressed in cyanidioschyzon merolae; the gene product localization and expression confirmed after 24 h of PEG-mediated transformation through immunocytochemistry (Allison et al. 1996). Stoppel and meurer 2012 reported a simple and inexpensive stable plastid transformation in tobacco where the leaf protoplasts were treated with the presence of the transforming DNA.

A. Represent basic design of a typical chloroplast transformation vector where between the two plastid regions both selection and expression cassettes are placed. The flanking regions of wild type plastid genome that are required to manipulate in order to ensure the crossover or genetic exchange that take place for the integration of the sequences of DNA. In expression vector, greenish arrows denote Promoter **(P)** and transcriptional direction, whereas red rectangle indicates terminator **(T)**. White circle and Black lines with arrows represent UTR and Homologous Recombination.
B. Transgene to be transfer.
C. Transgenes and vector coated with gold particles.
D. Gene gun/Particle Bombardment for bombarding the coated transgene and vector with gold particles into the targeted tissues.
E. Transformed leaves through biolistic transformation

Table 12.3 Commonly used transformation methods of chloroplast with selection conditions

Species of plants that was transformed	Methods of DNA delivery	Processes of selection	Genes expressed	Reference (s)
Chlamydomonas reinhardtii	Particle Bombardment	Photosynthetic Competence	*atpB*	Goldschmidt-Clemont (1991)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Spectinomycin	*rrn16*	Svab et al. (1990)
Tobacco (*Nicotiana tabacum*)	PEG	Spectinomycin	*rrn16*	Maliga (1993)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Kanamycin	*nptII*	Carrer et al. (1993)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Spectinomycin	*uidA*	Iamthan and Day (2000)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Spectinomycin	*Bar and aadA, Bt*	Daniell and DeCosa (2001)
Arabidopsis thaliana	Particle Bombardment	Spectinomycin	*aadA*	Sikdat et al. (1998)
Potato (*Solanum tuberosum*)	Particle Bombardment	Spectinomycin	*aadA and gfp*	Sidorovo et al. (1999)
Oryza Sativa (Rice)	Particle Bombardment	Spectinomycin	*aadA and gfp*	Khan and Maliga (1999)
Lycopersicon esculentum	Particle Bombardment	Spectinomycin	*aadA*	Ruf et al. (2001)
Oilseed rape (*Brassica napus*)	Particle Bombardment	Spectinomycin	*aadA & Cry1Aa10*	Hou et al. (2003)
Cotton (*Gossypium hirsutum*)	Particle Bombardment	Kanamycin	*aphA-6*	Kumar et al. (2004b)
Soybean (*Glycine max*)	Particle Bombardment	Spectinomycin	*aadA*	Dufourmantel et al. (2004)
Lettuce (Lactuca sativa)	PEG	Spectinomycin	*aadA and gfp*	Lelivelt et al. (2005)
	Particle Bombardment	Spectinomycin	*aadA and gfp*	Kanamoto et al. (2006)
Soybean (*Glycine max*)	Particle Bombardment	Spectinomycin and diketonitrile	*aadA,hppd*	Dufourmantel et al. (2007)
Tobacco (*Nicotiana tabacum*)	PEG	Spectinomycin and Streptomycin	*Rps12, rrnS, des*	Caraig et al. (2008)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	7-Methyl-treptophan and 4-Methylendole analogs	*ASA2*	Barone et al. (2009)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Spectinomycin and autoluminescence	*AadA, lux operon*	Krichevsky et al. (2010)
Alfalfa (*Medicago sativa*)	Particle Bombardment	Spectinomycin	*aadA*	Wei et al. (2011)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Streptomycin, Spectinomycin and D-valine or D-alanine	*aadA, dao*	Gisby et al. (2012)
Tobacco (*Nicotiana tabacum*)	Particle Bombardment	Cytokinine-free	*ipt*	Dunne et al. (2014)

F. Embed of bombarded explants (Leaves) to regeneration medium harbouring proper antibiotic (Example-Spectinomycin).
G. Antibiotic (Example-Spectinomycin) suppresses the formation of callus, green coloration and regeneration of shoots from bombarded explants on shoot regeneration medium. Transformed tissues can be identified as green shoot or calli.
H. In transplastomic sector, Chimeric Shoots is visualized by the accumulation of GFP.
I. Natural Antibiotic resistant: Top portion shows the sensitivity of Mutants, but bottom part denotes the antibiotic resistance of transplastomic clones during the culture condition with a selective antibiotic.
J. Regeneration round from shoot to achieve homoplasmy condition.
K. Regenerated mature plant.
L. ptDNA sorting is accelerated by Chloroplast (CHL) and Proplastid (PP) and Transformed nucleoids is represented by red circles where as Blue circles denotes non-transformed circles. PtDNAs are loyal to membranes by proteins (*Black dot*). (1a): transgenic bearing transformed plastid (homoplastomic) Progenitor and (1b) represent the wild – type of proplastid, Nucleoid 1 is heteroplastomic in nature and pro-plastid containing same plastomic consequence (homoplastomic) differentiate into the chloroplast, on the other hand, proplastids wild in nature (2, 1b) are sensitive to antibiotic and shows slow division.
M. During Chloroplast (~100 per cell; *Green*ish and Elongated) to Proplastid (~10–14 in every meristematic cell; Greenish and oval) alternation, Plastid number reduced and lack of exact cytoplasm duplication enhance to achieve homoplastomic condition of the cells. Mesophyll cell of leaf having both transformed chloroplast and Nucleus (Nu) (has shown in top). 1a: Nature of meristematic cells is heteroplastomic and meristematic cell having only transformed chloroplasts (1b); denotes wild-type of plastids yields from the cleavage of cytoplasm. Cell 1: depicts the progenitor of mesophyll cells of homoplastomic origin (1c).
N. Strategic consequences in chloroplast genome during the modification of endogenous genes.
   (a) To make the gene into inoperative manner (knockout) by the selectable marker gene cassette aided breakage of the reading frame (aadA; Red box). On the other hand, from the cloned ptDNA fragment, the gene of interest (Green Box) can be excised that also can be replaced with the marker cassette. Blue box representing both left and right flanks. Double cross over indicate possible recombination event leading to successful plastid transformation that is being shown by dashed arrows.
   (b) By the site-directed mutagenesis, induction of plastid gene mutation: gray dashed arrow denotes the inner region of mutation (M) and the aadA gene.

(c) Co-Transformation mediated mutation induction into plastid genes: For the insertion of aadA gene in close proximity, it is necessary to interfere the expression of genes located in operon. Mutation of target genes and the co-integration of aadA gene will be occurred in 5–20% of the transplastomic clones.

12.6 Comparative Advantages of Chloroplast Genome over Nuclear Genome

Due to several outstanding alternatives to nuclear transformation, transformation of plastid has become an important tool for the changing the genome pattern of some commercial crop plants (Wang et al. 2009). Plastid genome with high ploidy number allows the high level of protein or transgene expression (up to 1–40% of TSP) (Roudsari et al. 2009). According to the report of Daniell et al. 2002 and Hou et al. 2003, concentration of protein expression by plastid transgene is much higher up to 18% while transgene from nuclear transformation results in 0.5–3% of TSP. Every plant contains multiple copies of plastid transgene that affected by pre or post transcriptional silencing that leads to greater production of expressed proteins. According to Maliga 2001, Plastid transformation technology is capable to ensure the expression of multiple genes from polycistronic mRNA, avoid the epigenetic effects and gene silencing and it also offers huge utility over the nuclear genome that can be enlisting bellow (Table 12.4):

Table 12.4 Generalized comparisons between chloroplast and nuclear transformation

Chloroplast transformation	Transformation of nuclear genome
As a result of maternal type of inheritance pattern, reduced dispersal of genes in the environment is occurring	Having paternal inheritance, it shows the gene dispersal in the nature
Higher expression and accumulation of foreign protein is ensured by the presence of multiple copy (high ploidy number) plastids	Nuclear transformation does not reveal high copy number that leads the low manifestation and collection of foreign proteins
Extensive and abundant manifestation of genes from a single outcome	Single transformation event is not capable to yield/express abundant copy of genes
Multisubunit complex protein expression from polycistronic mRNAs with only single promoter is possible	More than one promoter is required for each gene to continue the manifestation of respective sub-units
Synchronous manifestation of genes takes place when it contains prokaryotic system of gene expression	No simultaneous gene expression is occurred due to the absence of primitive type of gene expression machinery
Site (Position) effect and silencing of gene is avoided by Homologous recombination	Due to Random integration, Position effect and silencing of gene is present
The lethal effect is minimized because of the existence of compartment in chloroplast	Toxic proteins collection in the cytosol is lethal in nature
During one transformation event, transgenes can be arranged in operons introduced into the genome	Independently insertion of the transgene into genome

12.7 Unique Utilities Offered by Chloroplast Genome Engineering

12.7.1 Containment of Natural Genes

In cases of cultivation of transgenic plants in the field, crossing and their dissemination into wild species is the major concern through which the pollen mediated gene integration and exchange of genetic characteristics of plants with their relative species can be possible (Stewart et al. 2003). Transformants of canola (*Brassica napus L.*) from the nuclear origin to weeds, genes responsible for the developing resistance against three herbicides (Rounddup, Liberty and pursuit) can be mentioned as an ideal example (Steward 2000). During the release of GMO plants in the environment or field condition, containment of transgene has drawn the attention of the scientists over the world and in this consequence, transforming non-nuclear genomes (plastid and mitochondrion) can possess a mechanism regarding the gene stifle because of their maternal type of inheritance pattern (Jaffé et al. 2008). As for example, the inheritance pattern of major angiospermic plant is eminently maternally inherited and it reveals that the transgene incorporated into the genomic region of the plant species should be in principle not be through the dispersion of pollen (Greiner et al. 2015). Albeit, the containment of gene is not utmost, diffusion of transgenic plastids to tobacco pollen has been recorded ranges between 0.00024-0.008% (Svab and Maliga 2007) and in *Arabidopsis thaliana* it was recorded about 0.0039% (Azhagiri and Maliga 2007). Because of the necessity of absolute gene containment, new approaches have been manifested depending on the generation of transplastomic biomass under the *in-vitro* (sterile and glassware) condition. PtDNA can be incorporated within the nuclear genome (Wang et al. 2012) that uplifts the probability by which the transgenes essentially compacted into the plastome and it can be disperse as like as an ideal type transformant of nuclear origin (Gilbert 2013).

12.7.2 Removal of the Barrier of Random Integration by Ensuring the Site-Specific Incorporation of Extra-Chromosomal DNA into the Chromosome

According to the Fig. 12.2, if the gene of interest gets site-specific integration into the scheduled site of the plastosome, it confers the avoidance of several issues like silencing of genes and unexpected mutation because of the amalgamate (random integration) of transgenes. For the nuclear genome (Vieler et al. 2012), homologous recombination has been reported but in the entire standard *Agrobacterium* mediated transformation procedure the transgene leads to the random integration (Kohli et al. 2010) and probably the foreign genes goes under active interaction with native nuclear genes and due to the non-allelic mode of interaction the functions of native type genes can be hidden (Scheid et al. 1991). It's not been clearly identified and still regarding as a potent contravention which are inexorable for the transformation of nucleus (Qin et al. 2003) when the alien genes are introduced into the genome of plastids (Bock 2015). Except the alien genes integration, chloroplast transformation technology is still remaining most adjuvant means to investigate the role of PEP protein by the dint of the knockout creation and site-specific (oligonucleotide – directed) mutants (Bock 2015).

12.7.3 Engineering of Plastome Ensure Elevated Level of Protein Expression

Because of high copy number in plastosome, in comparison to nuclear expression, chloroplast transformation favours the high expression of alien proteins. For instance, the manifestation of enterotoxigenic *E.coli* β-subunit into the tobacco plastome was recorded about 0.01% of TSP (Haq et al. 1995) and on the other hand, through the manipulation of chloroplast genome 410-fold increasement in the same protein expression can be achieved (Daniell et al. 2001). To denote the extensive elevated level of alien protein expression several examples can be addressed where chloroplast gene expression in tobacco showed more than 70% of TSP. From the toxic effect of that protein it is required to protect the plants and in these cases the expression and confirmation of an alien protein into the chloroplast genome might also be useful. For example, in tobacco cytosol, the presence of even very small level of (0.3% TSP) cholera β-toxin showed stunted physiological growth of plant (Arakawa et al. 1997), on the contrary transformation of chloroplast results 14-fold higher level of expression and no adverse effect was found on plant growth and proliferation (Daniell et al. 2001). Chloroplast functions and plant fitness are greatly affected by the over expression of foreign proteins (Scotti and cardi 2014), for instance, C type tetanus toxin fragment expression at 25% of TSP (not at 10% of TSP) showed the detrimental affinity on the host plants growth and development (Tregoning et al. 2003). Same result was recorded in tobacco and it revealed that ~7% TSP in glutathione – S-transferase expression influenced the male sterility of cytoplasmic origin (Ahmad et al. 2012), but no remarkable effect was found at low level accumulation of protein. Through the sensible utilization of regulatory elements (Series of DNA that control the expression of gene), the procurement of foreign proteins can be increased or decreased several folds and the gene expression of chloroplast is highly controlled during transcriptional and translational levels (Maliga 2003).

12.7.4 *Engineering of Important Metabolic Cycles*

In order to ensure the accumulation of expected traits in plants, it is required the combined activation of several enzymes and metabolic pathways for the protection of biotic and abiotic stresses, enrichment of nutritional contents, huge metabolites production for the industrial utilization and for the better crop yields (Bock 2014a, b). For instance, in *Klebsiella pneumonia* the DNA accountable for the fixation of nitrogen coding enzymes is 24 kb in size and consist of 20 genes but on the other hand, in case of Streptococcus, the cluster of genes responsible for the polysaccharide formation is measuring about 25 kb in length and 16 genes are assigned with the structural pattern (Cieslewicz et al. 2001). Up to date, several lucrative metabolic pathways have been manipulated successfully into transplastomic plants to achieve several important biological parameters. These are includes (Table 12.5):

12.8 Beneficial Aspects of Transplastomic Plants in Agriculture

12.8.1 *Improvement of Agronomic Traits of Importance*

In order to confer the agronomic traits of importance in crop plants, Scientists have successfully engineered different genes in chloroplast, for example, Synchronous expression of protease inhibitors and chitinase have been appointed to produce various biotic and abiotic stress tolerant plants, especially in tobacco. By the dint of chloroplast genetic engineering, economically important agronomic traits like resistance to herbicide, insect pest and droughts have already been achieved. Herbicide tolerance is a most important trait of interest that has drawn the attention for plastid transformation and the creation of plants resistant to over dose of glycophosphate was ensured through the gene gun mediated transformation of plastid by the

Table 12.5 metabolic pathways found in Transplastomic plants

Pathways/Production	References
Polyhydroxybutyrate Production	Lossel et al. (2003, 2005)
The β-carotene content enhancement	Apel and Bock (2009) and Wurbs et al. (2007)
The introduction of mevalonate Pathways	Kumar et al. (2012a, b)
The atremisinic acid Biosynthesis	Saxena et al. (2014)
Higher yield of Vitamin-E in Tobacco	Lu et al. (2013)
Improved production of Vitamin-E in *Lactuca sativa*	Yabuta et al. (2013)
The expression of Dhurrin (a cyanogenic glucoside found in *Sorghum bicolor*)	Gnanasekaran et al. (2016)
Production of a Triterpene named Squalene	Pasoreck et al. (2016)

incorporation of genes harboring herbicide-tolerant properties (mutated) coding for EPSP synthesis.

12.8.1.1 Biotic Stress Tolerances

12.8.1.1.1 Increased Insect Resistance Through Transplastomic Plants

Unless extensive modifications are carried, transformation of gene of interest through the nuclear transformation to assure the resistance against insect pests usually yield very downcast level of gene expression, but the incorporation of the same gene into the plastosome ensures the high level of toxin accumulation (McBride et al. 1995). Leaves of transplastomic plant contain the high level toxic effect to the insect larvae those who feed on green tissues and injure the plants by chewing leaves and sucking sap. Main utility of incorporation of Bt toxin into the plastome ensure the elevated level accumulation of toxin protein (3–5% of TSP by plastid transformation but only >0.2% of TSP through the nuclear transformation) (McBride et al. 1995). Due to widespread adaptation of the technique, achievement of durable plastid transformation in any species other than tobacco (*Nicotiana tabacum*) is quite difficult and face hurdle to get satisfactory result (Gatehouse 2008). In cabbage genome, transformation of *cry1Ab* gene was successfully availed and the toxic protein was detected ranges between 4.8 and 11.1% of TSP.

12.8.1.1.2 Transplastomic Plants with Increased Disease (Pathogen) Resistance

Transplastomic plants offer a viable and alternative option to develop various bacterial and fungal disease resistant plant varieties. As for example, in tobacco, transplastomic plants developed by the incorporation of gene named *MSI-99* (antimicrobial peptide) into plastids showed resistant to *Colletotrichum destructive* (A fungal pathogen) (DeGray et al. 2001). Transplastomic plants can introduce a new and efficient horizon for the initiation of crop plant verities that will be capable to protect themselves against different bacterial and fungal infections. For instance, high expression of foreign gene (MSI-99) in plastid denotes 88% (T_1) and 96% (T_2) expression level against a notorious insect pest and another agrobacterium mediated transformation with argK gene in tobacco encoded ROCT (Hatziloukas and Panopoulos 1992) enzyme that revealed higher resistant (ranges between 83 and 100%) to *phaseolotoxin* where the wild type OCT showed only 22% efficacy rate. When *phaseolotoxin* was exogenously supplied to the wild type tobacco leaves, it shows chlorosis in 100% leaves but transgenic tobacco plant containing argK genes from *Pseudomonas syringe pv. Phaseolicola* was able to show resistance. With the expression of both entC, transplastomic plants developed through the biolistic transformation showed that the accumulation of salicylic acid is 1000 times higher than wild plants (Verberne et al. 2000). Of late, In order to avail pathogen and insect pest resistant tobacco plant (*Nicotiana benthamiana*) has been produced with a gene construct harbouring aadA marker gene combined with a stacking of gene containing potato sporamin, *CeCPI* (taro cystatin) and chitinase (isolated from *Paecilomyces javanicus*) (Chen et al. 2014). In a surprising manner, transgene of transplastomic plants express in both the leaves and root plastids that confer a high level of resistance against different insect pests, diseases and many abiotic stressors. Above mentioned results emphasize the extensive and still non-investigated dynamic characteristics of transplastomic plants in agricultural breeding that draw our attention towards the enhanced abiotic stress tolerance mechanisms.

12.8.1.1.3 Herbicide Detoxification by Transplastomic Plant

Achievement of sustainable resistance in plants against herbicides, especially against high level of Glyphosate through the over expression of mutant 5-enolpyruvyl shikimate-3-phosphate synthase (EPSPS) gene and it is one of the most significant transgenic traits in transplastomic plants. Nevertheless, from transformed nuclear genome there is a risk of gene escape through the pollen dispersal that create the 'Super weed' had guide to a substitute direction of expressing modified ESPSPS in plastid genome for gene compression (Chin et al. 2003) and similarly in tobacco plastid, the bar gene expression has been exhibited extensive herbicide resistance especially resistance against phosphinothricin (PPT) (Lutz et al. 2001). Another example can be found in tobacco where the genes contain resistance potentiality against herbicide, these include: *crtI* extracted from *Erwinia carotova* encode phytone, bxn gene isolated from *Klebsiella pneumonia* encode bromoxynil specific nitrilase exhibit tolerance to norflorazon and bromoxynil (Dufourmantel et al. 2007). To date, endeavors have taken with transplastomic plants to develop the abiotic stressor resistant plant species have been documented on Table 12.6 in a brief manner.

12.8.1.2 Abiotic Stress Tolerance

12.8.1.2.1 Drought and Salinity Tolerance

Plant plastids contains high potentiality for the modification of genetic constitutes of the basic enzymes those are related to the plant stress metabolism and up to date, staple crop plants including cotton and soybean successfully has been transformed that offered an efficient and new direction to develop abiotic stress tolerant transgenic plants. First attempt was launched to produce transplastomic tobacco plant by the incorporation of CMO (Chlorine monooxygenase) and Betaine aldehyde dehydrogenase (BADH) pathway directed to the plastid genome that was successfully used for the development of salt, drought and low temperature tolerant plants and exhibited enhanced tolerance against abiotic stresses. With the presence of CaMV 35S promoter in transformation vector, transformation of tobacco was done

Table 12.6 List of abiotic stressor resistant plant species achieved through the chloroplast transformation

Species of plant used in experiment	Transgenes	Protein expression level (% of TSP)	Affected insect pests or pathogens (bioassays)	References
Resistance to insect pests				
Nicotiana tabacum (tobacco)	*Bt cry 1A(c)*	*3–5%*	*Heliothis virescens, Helicoverpa zea, Spodoptera exigua*	McBride et al. (1995)
	Bt cry2Aa2	*2–3%*	*Heliothis virescens, Helicoverpa zea, Spodoptera exigua*	Kota et al. (1999)
	Bt cry 2Aa2 Operon	*45.3–46.1%*	*Helicoverpa zea, Spodoptera exigua, Heliothis virescens,*	De Cosa et al. (2001)
	Bt cry 1Ia5	*3%* (Approxt.)	*Heliocoverpa armigera*	Reddy et al. (2002)
	Btcry1C	*1.1–4%*	*Spodoptera litura*	Lin et al. (2003)
	Bt cry9Aa2	*10%* (Approxt.)	*Pthorimaea operculella*	Chakrabati et al. (2006)
	Pta (Agglutinin)	*5.2–9.3%*	*Spodoptera exigua, Myzus persicae, Bemisia tabacci, Helicoverpa zea, Heliothis virescens*	Jin et al. (2012)
	Bt cry 1Ab	*45–46 ng mg^{-1} fresh weight*	Not tested	Mirza and Khan (2013)
Brassica napus	*Bt cry1Aa10*	a	*Plutella xylostella*	Hou et al. (2003)
Glycine max	*Bt cry1Ab*	a	*Anticarsia gemmatalis*	Dufourmantel et al. (2005)
Solanum tuberosum	Hairpin dsRNAto β-actin gene of CPB	0.4% of total cellular RNA (Approxt.)	*Leptinotarsa decemlineta*	Zhang et al. (2015)
Disease (pathogen) resistance				
Nicotiana tabacum (tobacco)	msi-99 (*magainin 2 analog*)	a	*Colletotrichum destructivum, Pseudomonas syringae pv. Aspergillus flavus, Fusarium moniliforme, Tabaci, Verticillum dahlia*	DeGray et al. (2001)
	pe1B, pe1D (*pectate lyase*)	*26 and 32 units g^{-1} fresh weight*	*Erwinia cartovora*[b]	Verma et al. (2010)
	RC101 (*Retrocyclin*)	*32–38%*	*Erwinia cartovora*[b], *tobacco mosaic virus*	Lee et al. (2011)
	PG1 (*protegrin*)	*17–26%*	*Erwinia cartovora*[b]	Lee et al. (2011)
	Pta (Agglutinin)	*5.2–9.3%*	*Erwinia cartovora*[b], *tobacco mosaic virus*	Jin et al. (2012)
	Cpo (*chloroperoxidase*)	a	*Alternaria alternata*	Ruhlman et al. (2014)
Nicotiana benthamiana	Sporamin, CeCPI, Chitinase	*0.85–1% for each protein*	*Alternaria alternate, Pectobacterium cartovorum* subsp. *Cartovorum*	Chen et al. (2014)

Bt Bacillus thuringiensis
[a]Denotes adequate expression of genes that has been observed, but no quantification
[b]Indicates Erwinia cartovora that is the previous name of Pectobacterium carotovorum subsp

to achieve BADH and Spinacia oleracea was used as an origin. On the other experiment tobacco was also transformed with cDNA to avail BADH where the Beta vulgaris was used as an origin. BADH was produced in tobacco plastid, on which for the conversion of betaine aldehyde to betaine BADH was used as converter that assured good resistance potentiality to betaine aldehyde (Table 12.7). On the other hand, from *Spinacia oleracea*, cDNA for chlorine monooxygenase was incorporated into tobacco genome and synthesized enzyme was deported to plastid and finally produced transplastomic plants pretend high level photosynthesis and exhibited elevated yield of photosynthesis in the presence of 150 mMNaCl (Zhang et al. 2008). As a conclusive comment, it can be predict that, glycinebetaine has response as consistent solute and if the localization and incorporation of both BADH and CMO pathway is possible, engineering of glycinebetaine into non-accumulation will be fruitful. *George* et al. showed that, *localization* of chloroplast and glutathione S-transferase that is induced from axin and source of *Prosopis juliflora* that has been avail from a phreatophyte ensure the drought tolerance capability in tobacco.

Table 12.7 Improved resistance against different Abiotic stressors

Plant species used for study	Transgenes	Stresses	Stress treatments	References
Nicotiana tabacum (tobacco)	Trehalose phosphate synthase (TPS1)	Stress from drought and osmotic parameters	Drought duration: 24 days Chemical: 6% PEG	Lee et al. (2003)
	merAB operon	Stress from heavy metal	400 Mm phenyl-mercuric acetate, 300 Mm $HgCl_2$	Ruiz et al. (2003) and Hussein et al. (2007)
	Fatty Acid desaturation (des)	Stress from chilling and cold	Leaf discs at 4 °C for 72 h, Seedlings at 2 °C for 9 days	Craig et al. (2008)
	Aspartate Decarboxylase (panD)	Stress from high temperature	40 °C for 10 h per day during 1 week, or 45 °C for 4 h	Found and Altpeter (2009)
	Metallothionein (mtl)	Stress from heavy metal	Leaf discs up to 20 Mm $HgCl_2$for 10 days	Ruiz et al. (2011)
	otsBAoperon (Trehalose Phosphate Synthase)	Salt induced Stress	300 mm NaCl	Bansal et al. (2012)
Daucus carota (carrot)	*BADH* (Betaine Aldehyde Dehydrogenase)	Salt induced Stress	Maximum 400 mm NaCl for 4 weeks	Kumar et al. (2004a)
Nicotiana benthamiana	Sporamin, CeCPI, Chitinase	Stress from Salt, Osmotic and Oxidative parameters	Maximum 400 mm NaCl, 3% PEG, 10Mm Paraquat	Chen et al. (2014)

PEG Polyethylene glycol and *PAR* Photosynthetically active radiation

12.8.1.2.2 Tolerance Against Temperature Stress

Increased level desaturation of fatty acid outcome as means of elevated nutritional value and mostly confer tolerance for the membranes unto temperature stress. Tobacco plants expressing desaturase genes include Δ9-stearoyl-ACP denaturase and Δ9-acyl-lipid desaturase isolated from *Solanum commersonii* and *Anacystis nidulans* respectively showed elevated fatty acid unsaturation levels both in leaves and seeds in a study that ensure proof of its efficacy (Craig et al. 2008). In some plant species, B-Alanine, a vital non-protein type of amino acid serves as a pioneer for β-alanine betaine and plays role as tolerant against abiotic stresses. *E.coli* gene (*panD*) encoding L-aspartate-α-decarboxylase is responsible for the L-aspartate decarboxylation to β-alanine and compared with non-transformed plants under stress condition transplastomic plants over express the *panD* that increase the heat tolerance and 30–40% higher biomass (Fouad and Altpeter 2009).

12.8.1.2.3 Anthropogenic Pollutants, Phytoremediation

One important portion of abiotic stressors is anthropogenic pollutants, as for examples, diverse herbicide resistant transgenic plant encoded in nucleus is commercialized. As a selective agent herbicide can be used and many extensive efforts have been advertent to produce transplastomic plant with resistant to Glyphosate (Roudsari et al. 2009), Phosphinothricin (Ye et al. 2003), Sulcotrione, Isoxaflutole (Dufourmantel et al. 2007), Chlorophenylurea (CPTA) pyriminylcarboxylate, imidazolinone and Sulfonylurea and paraquat (Chen et al. 2014). Compared with transgenic plant over expressing in nuclear gene, the transplastomic plants over expressing *epsps* gene (a mutant) in the chloroplast genome manifested 250-fold of EPSPS protein (Ye et al. 2001). To develop a new non-antibiotic marker gene basic research revealed D-alanine resistant transplastomic plants (Gisby et al. 2012) that opens an eco-friendly possibility to initiate D-alanine derived herbicides. In a similar way, with increased salt tolerance, the chlorine tolerance transplastomic tobacco lines may instigate the introduction of chlorine based herbicides.Besides the herbicides, including different metal compounds diverse anthropogenic pollutants recount as a potential threat to durable agriculture. The initiation of transplastomic plants by the successful integration of a native operon harbouring the mercuric ion reductase genes of bacteria (*mer A*) and organomercurial lyase (merB) is resistant to organomercurials and mercury salts ($HgCl_2$) illustrate as an example for transplastomic plants mediated phytoremediation (Hussein et al. 2007). Freshly, it should be accentuate that, transplastomic tobacco plants enacts a vital means of phytoremediation and amass very increased level of Hg in the plant tissues even their aerial parts (Hussein et al. 2007). Hence, although this process is compatible to clean up the agricultural fields, but such kind of genetic alternation is perhaps convenient only for the non-edible crops basically when they ensure the tolerance against flora and get procurement of these devastating compounds in edible plant tissues.

12.8.1.2.4 Oxidative Stress

Oxidative stresses set on by several biotic (Example-Pathogenic infections) and abiotic stressors (Examples-UV-ray, drought, cold, salinity, and excessive metal ions, pollutants and xenobiotics) affect the normal structural and functional parameters of plastids (Solymosi and Bertrand 2012). *Mdar* (Monodehydroascorbate reductase), one of the antioxidative enzyme of the ascorbate-glutathione cycle and over expression of *mdar* transgene into the tobacco plastid and the amalgamation of such plastid into *petunia* cells (Sigeno et al. 2009) revealed the possibility to have a defensive action against the oxidative stress. Other transgenes insertion are engaged with antioxidant defense system, as for example, mitochondrial superoxidase dismutase (*MnSOD*) in *Nicotiana tabacum* and glutathione oxidoreductase (*gor*) in *E. coli* drive the tolerance of paraquat-derived oxidative harm in transplastomic *MnSOD* tobacco plants. Transplastomic *gor* plants shows tolerance to heavy metal and in both transplastomic lines UV-B tolerance also observed that is related to the same antioxidant defence system (Poage et al. 2011). Likewise, from the efficient over expression of rice dehydroascorbate reductase (*DHAR*) and *E. coli GST* (glutathione-S-transferase) in the plastosome revealed elevated tolerance against abiotic stress (Martret et al. 2011). Enhanced oxidative tolerance also listed in transplastomic Nicotiana benthamiana and isofunctional flavoprotein (Chen et al. 2014). Cynobacterial flavoprotein (*fld*) also play vital role in stress tolerance mechanisms where the transplastomic tobacco leaves expressing *fld* ensured elevated tolerance against paraquat-derived oxidative stress likened to the non-transformed plants (Ceccoli et al. 2012).

12.8.2 Crop Quality Improvement Through Transplastomic Plants

Improvement of biosynthetic pattern of necessary amino acids, vitamin content and fatty acid quality in seed can be ensured by the transplastomic plants (Rogalski and Carrer 2011). In tobacco plastid, over expression of β-subunit from two units of anthranilate synthatase showed tenfold elevated production of free tryptophan in the leaves. In tobacco plastid, through the increasement of lipid quantity and with the help of rRNA promoter, over expression of aacD gene encoding acetyl-CoA carboxylase ensured good fatty acid oil content capacity of seeds. Transplastomic plants that yields high level of fatty acid in leaves, it was revealed into less senility of leaf and increased production of seed (Madoka et al. 2002). Carig et al. exerted improved unsaturation of fatty acid both in leaves and seeds through the over expression of Δ9-desaturase gene isolated from *Solanum commersonii* and *Anacystis nidulans* in tobacco. Very high manifestation of pro-vitamin-A into the plastid of tomato (Apel and Bock 2009) and astaxanthin (pigment of tobacco plants with human health interest) has increased the expectancy of transplastomic plant mediated metabolic engineering of nutraceuticals (Hasunuma et al. 2008).

12.8.2.1 Biofortification: Metabolic Engineering for Enhanced Nutritional Value

Including plastid transformation, an idea to produce edible crop plants with improved nutritional values is termed as Biofortification that may be attain by proper agricultural management, fruitful breeding programs or/several genetic manipulation strategies which enhance the metabolic activities of plants. Macro and micronutrients that leads intolerances, create toxicity and allergic reaction with the nutrients absorption can be considered and modify to increasement of food functionality (Newell-McGloughlin 2010). To alleviate diet-related diseases, diverse transgenic plants harbouring increased levels of phytonutrients have been developed and these comprise: high protein content in potato, increased amino acid availability, chlorine, florate anthocyanin, and vitamin-E, carotenoid, and iron and zinc contents in many crop plants (Matto et al. 2010). Alike feat may be reached by plastid transformation engineering and as for example, at an estimated concentration of 300 Mm of ascorbic acid in chloroplast stroma is engaged in oxidative stress protection (Valpuesta and Botella 2004). A comprehensive account has been adopted in Table 12.8 that will demonstrate the efforts have been taken for the biofortification of common crops to enhance the nutritional values.

12.8.2.1.1 Mineral Content

Countries where plants are considered as a main source of diet and vitamins, deficiency of micronutrient is the prime health concern of that areas and among the world population 60% extensively suffer from iron deficiency, over the 30% of

Table 12.8 Improvement of nutritional values and productivity of crop plants through the chloroplast Engineering

Species of plants	Transgenes	Traits of plants tested	Findings during observations	References
Nicotiana tabacum (tobacco)	Anthranilate synthase α (*ASA2*)	Trp content	High level of Trp content in leaves and seeds	Zhang et al. (2001)
	(*accD operon*) Acetyl-Co-A carboxylase	FA content	High level of FA galactolipid content, High level of 16:3 and 18:3, Low level of 16:2 and 18:2 FAs in leaves	Madoka et al. (2002)
	(*hppd*) Hydroxy-phenylpyruvate dehydrogenase	Vitamin-E content	High level of vitamin A content and quality in seeds and leaves	Falk et al. (2005)
Solanum lycopersicum (tomato)	Bacterial lycopene cyclase (*CrtY*)	Provitamin A content	High level of provitamin-A through the conversion of lycopene to β-carotene in fruits	Wurbs et al. (2007)
Lactuca sativa (lettuce)	*crtW*, *crtZ* (see above), *idi*	Astaxanthin Production	High level of astaxanthin and astaxanthin FA esters in leaves	Harada et al. (2014)

global population is suffering from deficiency of zinc (Rawat et al. 2013). As a result of deficient status, deficiency of Iron or zinc turned them to sever health disorders such as weakness, reduced/compromised immunity, irritability, fatigue, hair loss, muscle wasting, high rate sterility and morbidity and even immature death in acute cases (Stein 2010). Consequently, vital aim of agriculture is to the production of biofortified crops through the breeding programs bearing elevated levels of important vitamins and minerals; however, plastid contains diverse metalloenzymes and plays a vital role to mitigate the iron homeostatic condition by choosing extra iron as ferritin (Solymosi and Bertrand 2012). Moreover, in transgenic tobacco plants over procurement of ferritin also ensure resistance unto cold stress (Hegedűs et al. 2008). Because of its tremendous abundance, for the high level expression of peptides in the form of fusion products RuBisCO can be a charming target. Although transplastomic lines had normal RuBisCO level and activity with polyhistidine – tagged *rbcl* transgene but they accumulate more amount of zinc compared with non-transformed lines on zinc enriched medium (Rumeau et al. 2004). It is remarkable to hints that compared to wild-type plants application of molecular approaches such as the expression of therapeutic agent having anticancer properties and copper type protein named azurin, revealed in twofold increased accumulation of copper in transplastomic chloroplast (Roh et al. 2014).

12.8.2.1.2 Carotenoid Composition

Carotenoids are tetraterpenes environ in plant photosynthesis and due to their antioxidant activities asserts several health benefits include: protective effect against human heart failure, particular carcinogenic condition and diseases related to the late age and acts as a precursor of vitamin-A (Hammerling 2013). It is obviously that, deficiency of Vitamin-A is more dominant health sickness in most one-third countries of the world and it leads diverse diseases like elevated respiratory, gastrointestinal and paediatric diseases and even in acute condition leads to dead (Ye et al. 2000). To combat against deficiency of vitamin-A in the developing countries, transgenic rice have been developed that is commonly known as Golden rice expressing genes related to carotenoid biosynthesis with targeting signals of plastid in the endosperm cell nucleus (Al-Babili and Beyer 2005). With elevated or increased carotenoid, endeavors to create transplastomic plants include: (a) raising the emergence of the biosynthetic precursors, (b) Modification of the regulatory mechanisms/enzymes of the pathways responsible for the biosynthesis, c. stirring the pathway unto the synthesis of compounds. Up to date, Kumar et al. 2012a, b incorporated the exhaustive pathway into the tobacco plastosome that revealed tumid cumulus of carotenoids and few more compounds includes: squalene, mevalonate, triacyl-glycerides and sterols found in transplastomic line denotes the perplexity of isoproprenoid biosynthesis and its pivotal role in the metabolic activity of plant.

12.8.2.1.3 Vitamin E Composition

Methylated phenolic compounds tocopherol and tocotrienols are collectively known as tocochromanols and among them which one poses vitamin activity is termed as vitamin-E and these tocochromanols represents vital lipid soluble antioxidant that are mainly synthesized by the photosynthetic group of organisms including cyanobacteria, algal species and plants and this Vitamin-E is essential for the protection of lipid peroxidation. Condensation mechanism of homogenetic acid with isoprenoid chains in plants is the active process to avail the tocopherols and tocotrienols and this tocopherols and tocotrienols contains charming nutritional values and especially due to the higher amenities of vitamin-E in human nutrition it is demand of the age to go for the extensive breeding program to produce plants ensuring elevated content of tocochromanols and in recent years several operations of genetic engineering level have been launched to achieve the goal (Karunanandaa et al. 2005). As the primary location of corresponding biosynthetic pathways of vitamin-E in the chloroplasts, for the improvement of vitamin-E content in plants transplastomic crops can be an alternative way of metabolic engineering of it. *Yabuta* et al. introduced transplastomic tobacco of 3 categories harbouring either γ-tocopherol methyl transferase (*tmt*) or tocopherol cyclase (*ttc*) to ensure the high level of vitamin-E content by chloroplast genetic engineering. Both of these tocopherol biosynthesis genes were isolated from *Arabidopsis thaliana.* Although the amount of tocochromanols in fruits largely depends on ripening stage and the types of cultivars, through the chloroplast biotechnology we can produce transplastomic plants with higher content level of vitamin-E.

12.8.2.1.4 Lipid and Fatty Acid Composition

Omega-3 (α-Linolenic acid) and 6 fatty acids (linoleic acid) are beneficial to human health in several ways on the other hand, polyunsaturated and long chained type of fatty acids (Arachidonic acid and decosahexaenoic) are required for disease prevention and developmental processes (Ulmann et al. 2014). For the normal physiological processes of plant fatty acids are essential and due to the localization of fatty acid biosynthesis machineries in plastid (Napier and Graham 2010), plants with enriched with lipid and fatty acids can be ensured by plastid biotechnology. Moreover, fatty acids and lipids are known as an antioxidant and it has major functions in diverse stress tolerance mechanisms, for example, elevated unsaturation condition of fatty acids may appear to develop cold stress tolerance of plants and also increased nutritional values (Craig et al. 2008). In tobacco, first attempt to engineer the lipid pathway through the transformation of plastid aimed to replace the endogenous plastid *accD* gene promoter that encode the β-carboxyl transferase subunit of the basic enzyme in de novo fatty acid biosynthesis named as acetyl-CoA carboxylase (ACCase) (Madoka et al. 2002).Under the strong rRNA promoter, transplastomic leaves over express the endogenous ACCase gene of plastid that ensure the increased leaf but decreased the starch content. It also elevates the fatty acid and lipid content but alters the fatty acid composition with high unsaturation levels compared with non-transformed plants. In transplastomic plants, the fatty acid level of the seed remains unchanged although they had twofold higher seed production ensuring improved seed oil yield (Madoka et al. 2002).

12.8.2.1.5 Transplastomic Plants as a Reservoir of Essential Amino Acids

Essential amino acids as for example, Tryptophan (Trp) has vital role for the physiological growth and development of infants and required for the nitrogen balance in adults. As the biosynthesis machinery of the fatty acid is plastid located, parallelly the synthesis of most important amino acids also plastid located. For the Trp biosynthesis, nuclear type of genes is responsible that encodes mRNAs and translates on cytosolic ribosomes and targets to chloroplast. As the mRNAs responsible for anthranilate synthase are huge in number in plastids, they control the Trp synthesis (Radwanski and Last 1995). In tobacco plastid, Trp biosynthesis pathway was engineered through the metabolic engineering process and anthranilate synthase (*ASA2*) sub-unit was inserted. Through this engineering it was revealed tenfold more increased free Trp in the leaves and the seed showed slightly increased level of Trp content (Zhang et al. 2001) and the plant showed improved resistance against 5-methyl-Trp (inhibitor of anthranilate). This process was based on toxic Trp and an indole analog was used as selective agents that govern the improvement of the transformation protocol (Barone et al. 2009). Previous studies revealed that due to the site specific integration of transgene into the plastome it can manifest the variability in the expression levels of different transplastomic lines. This consequence arise especially when it usually compare with the transgenic plants achieved by the random integration mediated nuclear transformation (Zhang et al. 2001).

12.9 Transplastomic Plants for Improved Photosynthesis

During the Photosynthesis, to assimilate the atmospheric Co_2 into food RuBisCo (Ribulose-1,5 bisphosphate carboxylase oxygenase) is the prime functional enzyme and this RuBisCo is basically formed with eight and equal number of sub-units and those are known as small and large sub-units respectively. Among the RuBisCo sub-units, large sub-units or rbcL is coded by the genome of plastid but the small sub-units named rbcS is coded by the nuclear genome. Primary initiation and modernization of transplastomic lines and the manipulation of genomic status of plastid has instigated the RuBisCo manipulation in higher plants. This manipulation has vital role in cases of deletion, mutation or rbcL gene replacement for the improvement of photosynthetic capabilities and uplifted carbon fixation (Whitney and Sharwood 2008). First RuBisCo manipulation in tobacco depicted autotrophic and fertile type of plants by using rbcM gene that was isolated from bacteria named *Rhodospirillum rubrum* and as a result several types of RuBisCo was found in replacement of rbcL gene of tobacco. For the expression of Rubisco subunits into transplastosome, Rubisco of higher plant can be replace by another Rubisco that is isolated from phylogenetically identical bacterium *Rhodospirillum rubrum* and *Methanococcoides* respectively (Alonso et al. 2009). There are two Rubisco subunits from sunflower and tobaccos named S and L respectively have been incorporated and a hybrid Rubisco has developed (Sharwood et al. 2008). For the extensive study on hybrid Rubisco synthesis process, hugely studied transplastomic tobacco line was generated through the plastid engineering. A Rubisco gene was isolated from *Rhodospirillum rubrum* bacteria and developed a transplastomic line expressing non-homology sequence for the re-introduction of Rubisco gene for the creation of genome diversification to avail homoplasmic lines (Whitney and Sharwood 2008).

12.10 Transplastomic Plants Ensure Cytoplasmic Male Sterility

For the hybrid seed production scheme of different crop plant, CMS system is consider as a vital breeding tool. In an attempt of metabolic pathway engineering of biologically ductile PHB (polyhydroxybutyrate) through the expression of phaA, phaB and phaC genes in tobacco plastid (Lössl et al. 2005) revealed the high accumulation of PHB in plastid ensured male sterility and terminated growth. Based on the previous studies, Ruiz and Daniell recorded that when the β-ketothiolase enzyme was encoded by the phbA gene and expressed in tobacco plastids, it was manifested by 100% male sterility in plants without having any pleotropic effect (Ruiz and Daniell 2005). This type of study with transplastomic plants for the male sterility in plants was conducted for the first time and its achievement was satisfactory that can provide much more amenities to introduce the hybrid varieties in the near future.

12.11 Transplastomic Technologies Can Facilitate the Research on RNA Editing

To understand the RNA editing process, transformation of plastid played a vital role and editing of RNA in the plastid genome of plants included in higher order engage only C to U metamorphosis. Higher plants RNA manipulation firstly introduces in 1991 and since then complete information is available only for the editing site of plastid photosynthetic gene *psbL* in which at the mRNA level of codon for the translation initiation was initiated by the ACG codon conversion to the AUG codon. Most information for the involvement of protein factors of higher plant plastid is indirect and the presence of species, organs and site specific factors was supposed from the genetic experiment. In spinach, the first proof for the species – specific transfactor edition was achieved during the incorporation of psbE editing sequence into the plastid of tobacco. It was not edited without the cell fusion was conducted by the nuclear transfactor of spinach (Bock and Koop 1997) and when the *coxII* sequence of mitochondria was manifested in tobacco chloroplast the evidence of organelle-specific factors was attained where any single site of seven was not edited. On the other hand, from the antagonism between native and transgenic mRNAs the existence of site-specific factors was established. Assignment of group specific response to 2–3 nucleotides was performed within the well studied cluster NtrproBC473, NptsbLC2 and Ntrps14C80.Three techniques were used for the editing of Mrna in plastid transformation: minigenes, fusion during translation with the reporter genes and editing segment incorporation in the 3′-UTR. In cases of plasmid pRB51, with the XbaI-*BamHI* fragment the segment used in genome edition easily can be cloned. Further studies in near future will emphasize to understand the utility of editing of RNA into plastid and edition of RNA can act as a driving force and it will impart numerous copies of proteins from the identical gene.

12.12 Productions of Pharmaceutical Vaccines

Transformation of desired genes in chloroplast has adopted a colossal attention in the pharmaceutical industries because of its high elevated number of plastids DNA that facilitate large production of vaccine protein. Furthermore, it reduces the limitations accrue to costs of production and purification of the chemically synthesized vaccine, thus could serve as a source of affordable vaccine to the masses in developing countries. The principle integrates the desired genes encoding the antigen protein (bacterial and viral antigens) for specific disease into the chloroplast genome of a plant and appeared in edible tissues to form immunogenic proteins. However, due to lack of glycosylation mechanism in the plastid, the expression of antigen in plastid is limited to nonglycosylated proteins (Budzianowski 2015). There has been remarkable progress in the application of plant chloroplast as bioreactor since it was confirmed that plant can induce significant immunogenicity. Arntzen 2015 suggested that there were no implicit limitations of replication of this incorporated genes in plants when they found that the HBsAg formed in transgenic plants as anti-genetically and apparently same to the particles of HBsAg resulting from human serum and recombinant yeast. Because ELISA harboring a monoclonal antibody subjected to counter HBsAg that has been detected from human serum exposed the existence of HBsAg in altered leaves extracts at levels that relates with mRNA plenty. According to Farran et al. 2010, Vaccine antigen for *Vibrio cholerae*, was introduced in chloroplasts lead to about 31.1% TSP. A 2L21 peptide (an epitope of animal vaccine) that contain protect properties for dogs against virulent canine parvovirus (CPV) was introduced into tobacco genome as a fusion protein along with CTB and GFP (green fluorescent protein) (Madanala et al. 2015). LecA, a possible target having the blocking property against the bacterial amoebiasis, was incorporated into chloroplasts that yields 6.3% of TSP or 2.3 mgLec/g of leaf tissue (Mayfield et al. 2003). When secretory protein, human somatotropin was express in chloroplast**,** as compare to nuclear transformation higher concentrations of recombinant protein accumulation (more than 300-fold) was produced (Tran et al. 2009). As well as other bacterial and virus antigen in various plant plastid, HIV-1 p24 antigen has been produced in the high-biomass tobacco cultivar (Tran et al. 2013) resulted to higher total soluble protein. Despite huge success in the plant mediated pharmaceutical vaccine, it does not correlate to high clinical trials. However, a clinical success was recently reported in ZMapp created by the systematic selection of antibodies components generated by rapid transient expression procedure in tobacco species against Ebola virus disease (DeGray et al. 2001; Staub et al. 2000). Antigens are currently co-expressed with adjuvants to facilitate the transport of the antigen and enhance the immune response against a given antigen. Transgenic chloroplasts are employed as bioreactors for the synthesis of hybrid protein. By cloning a gene from *Withania somnifera*, Koya et al. 2005 has investigated an industrially important recombinant SOD (Superoxide dismutase) where Cu/Zn SOD was encoded into a transformation vector that was developed for the chloroplast genome engineering. As their findings, they have concluded that the leaves of transplastomic plants expressed the recombinant SOD near about ~9% of the TSP and the pure chloroplast manifested recombinant SOD up to ~4600 U/mg that establish the potentiality of chloroplast genome engineering to produce recombinant SOD in a economical pint of view.

12.13 Conclusions and Future Perspective

With the course of time, Presently, Plastid genome has been turned into a lucrative target to improve several biological properties like photosynthesis and crop quality. By ensuring the proper implementation of mentioned beneficial aspects of plastid transformation it is possible to introduce a new horizon in the field of agriculture. Besides the photosynthetic pathways of chloroplast, there are several biosynthetic pathways with a low amount of regulatory proteins like TRXs (Thioredoxins), FTR (ferredoxin-thioredoxin reductase) and NADPH-dependent thioredoxin reductase (NTRC). Over expression of such protein could be explored for plant trait improvement, for instance, that boosting the activity of these TRXs may promote biosynthetic activities in chloroplasts and enhance plant growth (Wang et al. 2009; Wani et al. 2015; Daniell et al. 2016). Over expression of caffeic acid O-methyltransferase in transgenic rice chloroplast was reported to increase melatonin production in chloroplasts via the 5-methoxytryptamine pathway thus exhibited improved seedling growth (Martin et al. 2002). In addition, chloroplasts are well equipped with metabolic pathways and has been found to produce retrograde signals to alter nuclear gene expression (DelCampo 2009; Daniell et al. 2016)**.** This specific property could explored to develop stress tolerance plant through targeted genome editing tool like meganucleases (MNs), transcription activator-like effector nucleases (TALENs), clustered regularly interspaced short palindromic repeat (CRISPR)-associated nuclease Cas9 and zinc finger nucleases (ZFNs). The targeted genome editing is a proven powerful genetic tool for studying gene function or for modifying genomes through the introduction of desire gene and correction of defective genes. However, there is little or no application of such targeted editing tools to modify several reported pathways in chloroplast genome. To our knowledge, there is no report of CRISPR/Cas9 technology to produce any model or stable staple plant lines through the targeted gene mutations in the chloroplast genome. Of late, there are huge evident of the origination of chloroplasts via an endosymbiotic consequence in which a free-living type of cyanobacterium and the CRISPR/Cas9 mechanism originated from type-II immune system of bacteria. Considering the fact that both have evolutionary relationship, we can take in consideration that optimization of this genome editing technology in chloroplast would be regard as a change maker in chloroplast transformation literacy to ensure enormous beneficial aspects. Due to direct and indirect effect of several factors, the global climate has drastically changed and it has a brutal impact on the global food security and total global food production has reduced in a sobering manner. For instance, within 1960–2000, the global food production dropped to 1.5% from 3.2% every year. Necessary biosynthetic pathways for the crop production lies in the plastid genome as a result, plastid biotechnology can be a potential choice to mitigate the world round food crisis and it will open a new possibility to feed the world population in 2050. As chloroplast contain hundreds copies of circular DNA and more or less hundreds chloroplast in every cell, through the over expression of tobacco plastid gene it has confirmed many therapeutic proteins, vaccine antigens and Biopharmaceuticals that we have tried to mention in our current review. For example, 11.1% of TSP human serum albumin, 7% of TSP somatotropin, 19% TSP of interferon-alpha, 6% TSP of interferongamma and 21.5% TSP of antimicrobial peptide is the important example of plastid engineering dedication to ensure utmost health security. Despite the above mentioned utilities, this technology has not been extensively extended to the major crops and with the proper utilization of this genomic engineering technology enhanced crop yield with sustainable insect pest control and sound health can be easier in the near future of the twenty-first century. Keeping in view the potential of transplastomic approach and its utilization in agriculture, it can be considered an ecofriendly technology with least environmental concerns.

Acknowledgements The research work in our laboratory on developing insect resistant Transplastomic potatoes is being supported by a grant (216O027) from the scientific and technological research council of Turkey (Tübitak). Md Jakir Hossain is scholarship holder from this grant. The support of Tübitak in terms of funding for our research activities is highly acknowledged.

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Chapter 13
Alternative and Non-conventional Soil and Crop Management Strategies for Increasing Water Use Efficiency

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Abstract Agricultural production is pivotal for sustainable supply of food, fiber and shelter. However, a complex plethora of biotic and abiotic factors coupled with climatic changes pose a major threat to sustainable crop production and global food security. Agriculture is the single major consumer of global fresh water resources, however, non-judicial use of fresh water and changes in the global hydrological cycle have put a significant pressure on fresh water resources from local to regional

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_13

scales. There is an urgent need to devise both efficient as well as practical crop and soil management strategies to enhance water use efficiency (WUE) in agroecosystems. A combination of soil- and plant-based factors affect WUE in cropping systems. Depending upon the region, both conventional and modern tools are proposed and effectively being applied to increase WUE in various crops, especially in the regions under greater threat of fresh water deficiency for crops.

13.1 Introduction

Agriculture plays a key role in the lives of humans and the basic needs of them depend on agriculture such as food, fiber and shelter. Unpredictability of natural and climatic factors including temperature, rainfall and atmospheric CO_2, productivity of agriculture is under immense pressure to ensure food security. Due to high demand for crop production with the higher cost of energy and the decreasing trends in farm income, severe economic problems for sustainable agriculture has started to emerge (Shah and Wu 2019; Lobell et al. 2011).

Our agricultural systems are heterogeneous in terms of the socio-economic status with historical, political and ecological context that is crucial to formulate locally adjustable strategies for the sustainability and resiliency of agro-ecosystems in the near future (Koohafkan et al. 2012). The production of cereal crops has been boosted by modern agricultural science and molecular biology technologies over the past few decades through the development of new germplasm, but there are evidences of yield plateaus or decreasing yield gains rate in recent years (Shah and Wu 2019). So modern breeding technology and innovative crop management practices are considered to overcome the barriers for increasing the crop yield.

Agriculture sector is more sensitive among many systems which are affected by weather and climatic changes (Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). In last few years, the concept of food security has increased due to the negative impacts of climate change (Tripathi et al. 2016). Due to climate changes, food productivity has reduced and also increased in price of food (Bandara and Cai 2014). Similarly, the growing population of human accelerates the effects of climate change and it is estimated that global population will meet historic mark about 9.5 billion by 2050 (Fahad et al. 2018, 2019a, b). To fulfill the demand of this large population, excessive amount of food will be required from the present level. Developing countries are more prone to climate changes impacts due to their warmer climate, extreme weather events and lack of resources for adaptation methods (Singh and Singh 2017; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib ur et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2017, 2016; Shah et al. 2013; Qamar-uz et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017).

However, humans need to ensure maximal amount of crop production with minimum of environmental degradation, so no single option can completely fulfill the nutritional needs of abruptly growing human population. Changing are required in the production, processing, storage and distribution in agriculture to achieve higher food demands for growing population that will be environmental friendly and socially acceptable methods which was observed in previous major revolution such as green revolution (Godfray et al. 2010).

In adaptation strategies, the biggest challenge will be water scarcity for food production especially for such countries which have limited water and land resources. Increase in water requirements for agriculture, threats to natural water resources and climate change predictions, water scarcity and reduced availability of water for irrigation will be the biggest issues for crop production in the near future (Shah and Wu 2019). The great challenge will be to increase food production with less water, particularly in countries with limited water and land resources, by focusing on techniques and cropping systems for higher water use efficiency (WUE).

The significant observable climatic changes include warmer temperatures, irregular rainfall patterns and intensities, and increased frequency and severity of extreme weather events. In such conditions the need of water becomes more severe and water available for plant transpiration and biomass production depends upon resource level and crop management strategies including cultivar choice. Water available for plant transpiration and biomass production depends upon several factors such as resources (soil water contents, rainfall, irrigation) and crop management practices (water use throughout the growing season and cultivar selection). Climate changes are anticipated to induce warmer temperatures, alter the rainfall patterns and increase the frequency and severity of extreme weather events.

To overcome the problem of water scarcity, soil and crop management practices should be adopted like we should improve the soil water holding capacity, techniques that would extract more water from soil profile with the help of roots or decrease in leaching of water, this all results in improving the ability of water use by the crops and suppose to improved crop yield. Better soil management practices also increase the organic matter of soil that results in improved water holding capacity. Soil management practices that improve the soil water holding capacity, enhance the ability of roots to absorb more water from the soil and decrease in nutrient leaching losses could all potentially have positive impacts on WUE, assuming these changes result in a concurrent increase in crop yield. Improved soil management practices that increase the organic matter content of the soil would have a positive impact on the soil water holding capacity (Hatfield et al. 2001).

13.2 Crop Production, Food Security and Global Climate Change

In the next few years it is estimated that human population will reach to approximately 9 billion that results in the need of 70–100% more food (Godfray et al. 2010; Tscharntke et al. 2012). In Asia much food is demanded due to increase in population and better capita with in communities having high income (Reardon et al. 2003). High production of food is necessary to fulfill the demand of population. However, resource limitation to poor households may limit food security through market and non-market channels even when food is surplus at global scale. For agriculture-based economies, food security is strongly dependent on local food availability and majority of food producers exchange food for cash, other commodities or labor, and the food accessibility component is of critical importance, especially in relations to diversity in dietary diversity requirements and nutrition (Gregory et al. 2005).

According to estimation of FAO, in 1996 population who was suffering from chronic hunger increased from 800 million to over a billion. Some regions with large population, highly poverty and large inadequate agricultural areas are due to improper market rates and high fluctuation in climate. Due to high variability in rainfall season and because of poverty, farmers avoid to grow crops which depend on rain. Climate change is of particular significance for these countries, which already grapple with global and regional environmental changes and significant inter annual variability in climate (Arndt and Bacou 2000; Haile 2005). Climate variability affects water cycle, production of crop and land degradation (Sivakumar and Ndiang'ui 2007). Due to competition among land, water, labor and capital for better improvement in productivity food insecurity has increased in several regions.

13.3 Effects of Climate Change on Agriculture

According to IPCC, low emission scenario even a 2 °C change in temperature affects farming system (Easterling et al. 2007). Climate change has ability to effect food production, crop productivity, livestock and fishery system. People who suffer already from food security are at high risk due to climate change (Liverman and Kapadia 2010) and because of it, it is difficult to nourish nine billion people till 2050 (Godfray et al. 2010). One reason of climate change is emissions of greenhouse gases and it has, directly or indirectly, effects on production of crops used as food, health of animals, changes in the pattern and interchange among food products. Farmers are more vulnerable to climatic instabilities because they face problem in availability and quantity of water enough for their requirement. High temperature on daily basis decreases the growth period of the crops. Precipitation and runoff from snow melting on mountains brought floods in some areas while droughts in others due to different weather events. It is difficult to make plans for such changing in water available resources and the depletion or recharging of aquifers along with such large population, urbanization and land use changes patterns (Duran-encalada et al. 2017). The alarming situation of water resources is going to becoming the main issue among the natural resources of twenty-first century. Therefore, we have to devise sustainable approaches or unconventional water resources for water management that fulfills the water requirement required for crops. Being society, we have to use appropriate plans and schemes, through which agricultural users adopt advanced irrigation techniques and practices to enhance irrigation potency and water productivity in agriculture (Evans and Sadler 2008).

13.4 Global Water Demand and Crop Production in Agro-ecosystems

In the future, the nations that are vulnerable to climate change impact will have to face more unpredictability in available water resources. On global level, only seven countries were water-stressed conditions for agricultural production in 1955, the number rose to 20 in 1990 and it is expected that by the year 2025, additional 10–15 countries shall among the list of water-stressed countries. According to different predictions 2/3rds of the global population could face water stressed conditions (Gosain et al. 2006). If we look at globally, many Arab countries rely upon the international water bodies to fulfill their demand. Arab countries don't have excess supply of water; that's why they mostly rely upon natural precipitation and water conservation techniques to fulfill their requirement. Nearly 190 billion people of different countries like Eritrea, Uganda, Rwanda, Burundi, Congo, Tanzania, Kanya, Sudan and Egypt are depended on Nile river basin. It is very difficult to adopt any strategy for the countries who depend on Nile river because they are among the most 10 poorest countries of the world because it requires investment. The areas of middle East and the OSS (Observatory of the sahara and the Sahel), with very least natural water resources will be affected the most (Misra 2014).

Sustainable water management is one of the greatest that our society is facing in the twenty-first century (World Economic Forum 2013). Water scarcity is the point at which all the users have combined effects on the supply or quality of water under fundamental institutional arrangements to the extent that the demand for all sectors and users, including the environment, cannot be satisfied fully with the available water resources. Global demand for potable water may increase by 55% till 2050 (UN Water 2006). Three key factors that will drive the future global water demand are: (1) population growth, (2) increasing wealth and (3) changing diet preferences. Till 2050, it is expected that world population to increase to 9.3 billion and 10.1 billion by 2100 (Hoekstra 2013). Increased income growth for many countries is also expected at the same time. In developing countries, income growth is linked with increased water consumption because of changes in the demand of water for food production, as well as for sanitation. As income growth swaying lifestyle preferences, it is also expected to change diet preferences. For example, in many regions demand is forecasted to shift mostly from cereal-based consumption to increases in vegetable oils and meat that are higher water-intensive commodities. As it is predicted that population will become double in the next 50 years that results in increase the consumption of vegetable oils and meat therefore the demand for food and feed crop will be doubled (UN Water 2006).

Therefore, agricultural activity holds the largest share in global water use. In the agricultural sector the share of water use rises sharply from the 1940s and by 2000 was estimated at 70 per cent of global total water consumption. This share of water use varies by region, and where agriculture is the major economic activity, estimates of agricultural water use range from 40% in countries that have developed economies and import food from other countries (UN Water 2006). In most parts of the world, production of agriculture is rain-fed. Irrigated land occupies around 20% of the world agricultural land, however, has expanded 117% since 1961 (FAO 2011). The world's largest consumptive water extraction is in irrigated agriculture sector. Irrigation water use depends on the crop water necessities and also the water accessible to crops. Agricultural production is the biggest water-consuming area where rice, wheat, roots and tubers, pulses and fruit and vegetables make up the major irrigated crops for global food supply. Irrigation water use pattern are different between crops and regions. Crops for livestock, pasture feed and other grain production require the highest levels of water application relative to lower water use product for irrigated fruit and vegetable crops. For a person's daily diet approximately 2000-3000 litres cu_3 of water is required to produce enough food. Irrigation has been growing strongly over the past 60 years. From the 1940s to 1960 different irrigation practices was adopted named as 'Green Revolution'. In terms of hectares of irrigated land, the largest irrigating countries are India, China, the USA and Pakistan respectively. From 1998 to 2030 it is predicted that irrigation has been expand by 20 per cent in developing countries while agricultural water demand increased by 14 per cent in the same time period (Wheeler et al. 2015).

In several regions of the world, climate changes have wide ranging impacts on each the water and agricultural sector (Falloon and Betts 2010). Global climate change has potentially strong effects on temperatures, annual rainfall patterns, and regional rainfall distribution cycle and increases in water demand. A number of these changes could already be occurring, though predictions of regional impacts are problematic at the best. Variations in climatic conditions is a significant problem for producers because they have started to experience decrease in the quantity and quality of water. The crops that grow at rates proportional to heat units are going to shorten growing season because of locally and high daily temperatures. Change in the temporal precipitation patterns and availability of water from mountain snowmelt have changed from historical norms, resulting in more intense and extreme weather events including droughts and floods (Evans and Sadler 2008). Continuous unmanaged water extraction from aquifers, in those countries that are already most vulnerable in terms of water resources, is due the use of strong technological instruments like deep tube wells and pumps. The natural balance of recharge and discharge of water bodies like rivers and canals is disturbed and this is because of excess drafting of water by these pumps (Misra 2014) (Fig. 13.1).

13.5 Water Use Efficiency: Concept and Application

Human needs water for their drinking purposes, industrial activities, agriculture, hygiene and recreational activities, for these activities availability of excess water resources is necessary. As the water resources changes due to changes in precipitation patterns, droughts and decreases in water aquifer; negative impacts are seen on the development of any society. However, water availability as well as water quality both considered as the essential risk assessment parameters and predictions relevant with global climate change (Duran-encalada et al. 2017). In agricultural system, due

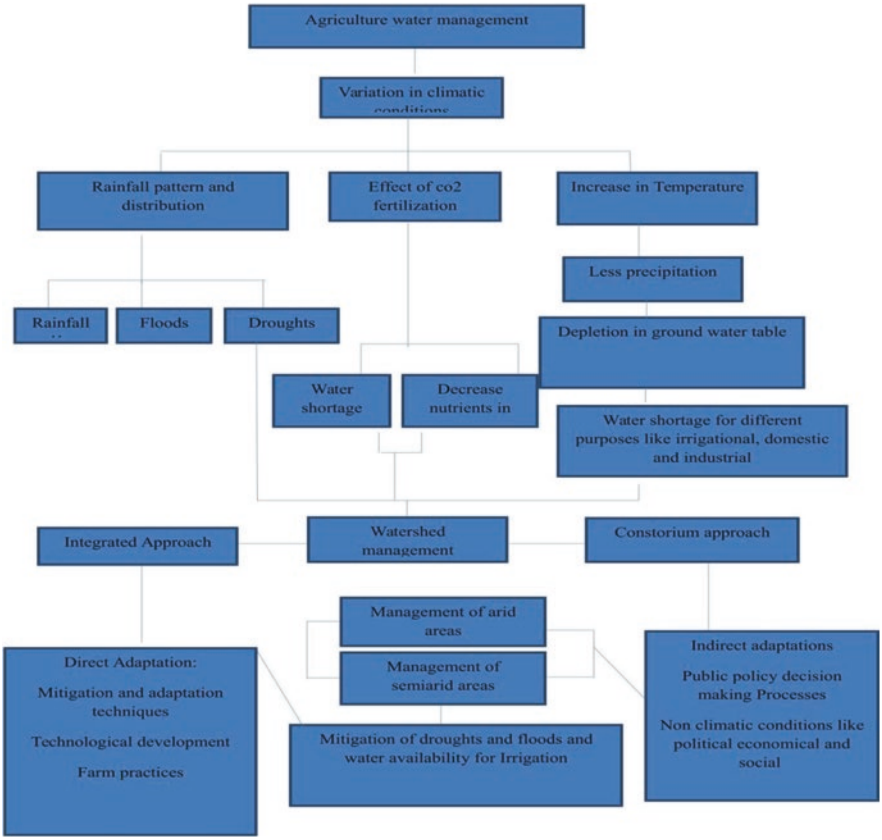

Fig. 13.1 Schematic diagram of water management strategies in agriculture

to low or irregular annual rainfall, water is becoming the most limiting factor. To meet the higher food demand and obtaining higher yield, high irrigation is necessary in such variable climatic conditions but fulfilling of these requirements water table and water quality both are decline. Therefore, to achieve higher crop productivity and efficient water use proper and sustainable irrigation strategies should be execute in agriculture system (Fang et al. 2010.).

Use of water in an efficient way is becoming an important question in such variable climatic conditions because of higher demand of water use and better environmental quality by human beings (Hatfield et al. 2001). In terms of agriculture system, water use efficiency (WUE) is generally defined as grain yield production per unit evapotranspiration (Fang et al. 2010). Water use efficiency (WUE) is also described as the crop yield per unit of water consumed. Water use efficiency can be expressed as:

$$\text{Water use efficiency}\ (\text{WUE}) = \text{Dry weight production} / \text{Evapo} - \text{transpiration} \quad (13.1)$$

Crop WUE is especially an important strategy in agricultural areas where water availability is limited or diminishing. Variations in WUE among many varieties is imperative which cannot be the changed with gene development. However, WUE could be enhanced under water-stressed conditions by increasing evapo-transpiration rates and transpiration and by improving crop harvest index (Zhang et al. 2012). Change in climatic conditions could also change WUE and it is a common observation that climate change adversely affect plant growth and WUE of the crop plants. The effects of WUE are seen on the leaf, plant and canopy level in response to changing climate.

13.6 Factors Affecting Water Use Efficiency

13.6.1 Soil Factors

- Soil water available contents
- Crop irrigation techniques

13.6.2 Plant Factors

- Crop species and cultivars
- Plant breeding and biotechnology (Singh et al. 2017)

13.7 Conventional Water Management and Water Use Efficiency

Many adaptation strategies such as the adaptation of regulated deficit irrigation in crop production, the use of novel water-saving practices, enforcement of laws and policies in water resource management have been used to save water in agriculture (Chen et al. 2018). Similarly with these techniques, some strategies that could also be used in water management such as redesigning of whole irrigation systems for greater efficiency, water that is degraded could be used again by successfully treating, minimizing evaporative losses, implemented site-specified applications, installation of managed-deficit irrigations, utilize engineering approaches to reduce water losses via leaching to unrecoverable sinks (Evans and Sadler 2008). For the maximum production of crops, among many affective approaches strip-intercropping is uses for improvement of water use efficiency in which early and cool season crop is grown with a late warming season, two crops in the same field. It has been investigated that enhancement of soil water conservation and use of available soil water and crop yield for whole system improved by implementation of intercropping (Chen et al. 2018). Intercropping is beneficial for WUE because it makes more efficient use of the natural resources such as land, light, water and nutrient with simultaneous benefits of promoting biodiversity, productivity, resilience and stability of agroecosystems (Singh and Singh 2017).

Other agronomic management practices are also helpful in water use efficiency like tillage practices for moisture conservation and enhancing crop yields. There are many positive effects of tillage in agricultural field such as providing most favorable condition for seed germination, proper growth of seedling, conserve soil moisture in unirrigated areas that enhance soil infiltration characteristics, facilitate sufficient soil depth for maximum root growth and fully placement of seeds and fertilizers in soil and control of weed in field. Deep tillage is beneficial for the monsoon rainfall (Meena and Singh 2013).

13.7.1 Selection of Crop and Variety

In rain fed areas, suitable crops and their varieties acclimatize the total amount and distribution of available water and agronomic practices are most important factors for the success of agriculture (Singh et al. 2009).

13.7.2 Planting Techniques/Methods

Suitable planting technique is another important practice in agronomic method for increasing the water use efficiency. For rainy season crops, the broad bed and furrows practices done in field. The field has prepared in ridges and furrows for some crops like maize, vegetables etc. Mostly the plantation of sugarcane is done in trenches and furrows. For the facilitation of two-way inter-cultivation, some crops are grown with equal intra-row and inter spacing such as tobacco, chilies and tomatoes (Singh et al. 2012).

13.7.3 Weed Control

The removal of weeds from the crops is one of the effective management techniques for water use efficiency. Their elimination in crops is necessary because weeds compete for the available resources like soil nutrients water and light. Water is the most limiting factor in agriculture except the high rainfall areas and the removal of weeds is necessary in water scares countries because for weeds the requirements of water is high as compared to nutrients than that of crops.

13.7.4 Rain Water Harvesting

Rain water harvesting is also an important technique through which we can enhance water use efficiency because the main problem in water management is seen at the time of seeding of the crops. For example, if the excess water is saved and stored for the sowing of other crops it will be beneficial for the proper germination of other crops. The major problem of water management is faced at the time of seeding of the crop. Management practices that helps in increasing infiltration, soil water management and decreases water loses as a result of evaporation, evapotranspiration and runoff enhances waters ability to retain in fields. There are two types of water harvesting in situ and ex situ water harvesting. The benefit of in situ water harvesting is not only to conserve soil, fertility and vegetation but also seen in periods of low rain fall when the available water is low for crop plants. The in situ water can be used then which results in high water available to the crops In ex situ water harvesting, water is stored and applied to the fields when the crops are facing dry spells and are at critical grown stages as additional water. In ex situ water harvesting water pond are formed by forming wall around the water coarse or by making a pit.

13.8 Alternative Soil and Crop Management Strategies

Increased in water demands for agriculture pose a significant threat to natural water resources and climate change scenarios strongly suggest water deficiency and reduced allocation of water to irrigation is predicted to happen in very near future. Water use efficiency can be improved through changing soil management practices that include altering soil properties to maximize water availability to plants because better monitoring of plants and soil health are the important components of improving WUE.

13.8.1 Increasing Soil Stored Water at Plant Sowing

Increased crop water availability and evapotranspiration can be achieved stored by enhancing the soil water retention capacity. Through the mechanism of deep tillage (e.g. paraplowing) during fallow-periods, with the view of increasing infiltration and reducing runoff, soil water retention capacity could be achieved. This practice is sometimes efficient and sometimes inefficient such as this practice yield limited-benefits in swelling clay soils. Clayey soil cracks under high temperature in summer and maintaining the high evaporation demand during in autumn period makes this practice inefficient. In comparison to shallow tillage or no-tillage, ploughing could lead to sub-soil desiccation in deeper layers during dry periods whereas more water is stored during wet periods. The areas where soil water conservation is important, more soil water storage is generally achieved by soil management techniques such stubble-mulching and minimum-tillage which have positive effects on promoting water infiltration and reducing evaporation.

13.8.2 Increasing Soil Water Extraction

When there is high condition of soil moisture soil tillage is a beneficial approach that encourages the root system to explore more soil volume which ultimately leads to higher transpiration (Hoad et al. 2001). Fertilizer application can also improve the cumulative water utilization by plants in small amounts by facilitating water extraction from depth and/or the amount of water extracted from specific soil layers. As water availability becomes limited along the depth gradient in dry regions, crop species and varieties with deep root system are recommended in such areas (Hoad et al. 2001). However, two problems are faced in such areas: (1) During the season, a rapid decline in stored water and a below-optimal distribution of water transpiration, and, (2) as root development progresses the wetting front in dry areas, it is highly unlikely that deep water reserves will be utilized each year.

13.8.3 Mulching Application

Soil water conservation in crop lands can be achieved using mulching technique which is considered the simplest and widely applied technique. In this method, layer of organic material is placed at the soil surface with the objectives to reduce soil moisture loss through evaporation. In addition, mulching can have other benefits such as reduction in weeds and increase in organic matter which enhance crop yields (Kimaro 2019).

13.9 Optimizing Seasonal Water Use Patterns

13.9.1 Crop Rationing

For the improvement of yield and water use efficiency, crop rotation is usually considered a sustainable approach because it also decreases soil erosion. By changing soil structure and aggregation, crop rotation improves soil quality and crop productivity (Singh and Singh 2017). The implementation of this practice changes water balance by decreasing crop water needs to the amount available for it from rain and irrigation. The main objective of this approach is to save water for the sensitive conditions by leaving enough water for grain filling.

13.9.2 Drought Tolerant Cultivars

The use of drought resistance crop cultivars and species is also beneficial adaptation method to increase WUE under water-deficient drought conditions. The agronomic parameters beneficial in plant breeding to develop drought resistance have been documented in relations with the target environmental factor. For example, the major traits for adapting to cold season grain legume species under low-rainfall Mediterranean-type climates are early flowering, pod and seed formation before the start of the terminal drought. Rapid development together with early ground cover and DM production allows greater water use in the post-flowering period: examples are pea and faba bean, as compared with other legumes (Debaeke and Aboudrare 2004).

13.10 Conclusions

Under the era of global environmental changes such as global climate change, increasing population and natural resource degradation, sustainable water management is one of the major challenges of the twenty-first century. With respect to food security, climate change is anticipated to affect the world disproportionately with stratifying patterns because the worst effects will be observed on poor, resource-limited and food insecure nations. As the population is increasing at a higher rate so it is necessary to increase agriculture production to meet societal needs; but the productive irrigated land and available water is declining. Thus, great challenge as a result of this, will be to increase food production with less water, especially in those countries that are with limited water and land resources, by promoting techniques and cropping systems of higher water-use efficiency. Therefore, water use efficiency could be enhanced by a number of methods like selection of crops and variety, agronomic practices, conservation tillage practices and moisture conservation practices. Advanced irrigation techniques and state of the art engineering delivery systems are also required to be fully implemented for successful deficit irrigation strategies. Precision agriculture tools such as site-specific water and nutrient applications could also play an important role.

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Chapter 14
Role of Biotechnology in Climate Resilient Agriculture

Sadam Munawar, Muhammad Tahir ul Qamar, Ghulam Mustafa, Muhammad Sarwar Khan, and Faiz Ahmad Joyia

Abstract "Resilience of agriculture to climate change" is a serious matter that should be the focus of all scientific, economic, political and social interventions to warrant sustainable life on this planet 'Earth'. Changing climate, somehow, affects all forms of life but its impact on plant life brings about the most conspicuous forfeits as plants are the main source of energy as well as matter fixation on earth. Hence, developing climate resilient plants especially crops is of pivotal importance for sustainability of all life forms. Biotechnological interventions have helped developing climate resilient agriculture. In this chapter, we have summarized the extensive topic of 'developing sustainable agriculture through biotechnological research'. After an epilogue on climate change impacts on global as well as country level, we have highlighted some significant examples from the areas of genomics, genetic engineering and genome editing for developing sustainable agriculture in the face of climate change.

Keywords Climate change · Biotechnological interventions · Agriculture · Carbon dioxide

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_14

14.1 Introduction

Changes in Earth's climate that persist for longer periods of time are collectively termed as 'Climate Change'. The Earth's climate receives most of its energy from the sun, retains some of it in different forms and gives off the extra energy to outer space. Proportion between the received and the released energy is termed as Earth's energy budget. Various anthropogenic factors cause retention of extra energy, shifting the energy budget towards positive and making the climate warmer. That rise in climatic temperature causes 'climate change' affecting whole life on earth including agriculture (Gornall et al. 2010; Garrett et al. 2016; Prasch 2013; Zhang et al. 2014; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b).

In coming decades, agricultural production needs to be doubled to feed exploding human population. Agriculture in its different forms is highly vulnerable to climate change and ecosystem disorders. Adaptive strategies are likely to have substantial benefits for some cropping systems under moderate climate change (Meinke and Stone 2005; Fahad and Bano 2012; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamaran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar-uz et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017). Development of crop varieties that are resilient to abiotic stresses is important under changing climate scenario. Agriculture can reduce poverty more effectively. It is projected that agriculture sector is better than other sectors as for as poverty alleviation is concerned. In Africa and Asia, about 1.8 billion people are projected to get suffered from fresh water shortage by 2025 (Varshney et al. 2011).

A significant rise in the emission of greenhouse gases within the earth's atmosphere leading to global warming such as, average increase in Global mean annual temperature is predicted at 0.8 °C till now. These emissions are known to enhance the global warming further 0.1 °C/decade for many decades. Major greenhouse gases emissions are still continuing across the globe over the last 25 years (IPCC 2014).

Changing climate directly affects all forms of life including microbes, animals and plants. Increase in atmospheric carbon dioxide (CO_2) has unpredictable effects on agriculture. On one hand, it causes a rise in photosynthesis rate and subsequent plant growth. On the other hand, it causes negative effects on nutritional quality of crop plants (Irigoyen et al. 2014). Atmospheric level of CO_2 in pre-industrial era was around 280 ppm which hovers around 397 ppm at the present day. This increase is significant. It is estimated that CO_2 concentration will get doubled by the end of this century (Parry et al. 2007). This has disturbed plants responses towards biotic as well as abiotic stress factors. For example, under elevated CO_2, severity of barley yellow dwarf virus attack on wheat has been reported to increase (Trębicki et al. 2015). Similarly, the interaction between heat stress and water scarcity influence carbon assimilation, leaf temperature and stomatal opening which indirectly affect photosynthesis rate and plant productivity (Feller 2016).

The simultaneous negative effect of drought and high temperature causes variation in plant development, growth and productivity specially in cereals (Ihsan et al. 2016; Zandalinas et al. 2018; Hlaváčová et al. 2018). Influence of heat stress has been studied in wheat (Porter and Gawith 1999; Kimball et al. 2016), maize (Bassu et al. 2014), rice (Zhao et al. 2016) and soybean (Deryng et al. 2014) and it has been observed that an increase of only 1 °C in seasonal temperature causes decrease in yield ranging from 3.1% in soybean to 7.4% in maize (Zhao et al. 2017).

Water scarcity intensely affects important physiological phenomena like flowering, pollination, and grain-filling in most grain crops. On the other hand, high relative humidity may damage plants by encouraging insect-pests attack (Rosenzweig et al. 2001).

Under changing climatic scenario, an increase in the intensity and frequency of pests, weeds and pathogens has been predicted depending upon geographical areas. Various modelling techniques predicted *Fusarium oxysporum* spp. posing risks to a various economically important crops in the regions of Middle East, Europe and North Africa between 2050 and 2100 (Shabani et al. 2014). Similarly, important diseases in wheat such as *Septoria tritici* Blotch (STB) and Fusarium head blight (FHB) are projected to infect crops in United Kingdom (West et al. 2012), China (Zhang et al. 2014) and several European Union countries due to the changing weather patterns (Fones and Gurr 2015).

Climate change has forced farmers to shift from conventional agricultural practices to modern climate resilient agricultural practices including diversifying crops, sowing drought and heat tolerant varieties, taking care of the soil and harvesting rain water for food security (Altieri and Nicholls 2017; Lin 2011; Lipper et al. 2014). Moreover, the adoption of climate resilient agriculture practices should also consider market risk, farm inputs, improved governance and organizations to improve their efficiency (Gentle and Maraseni 2012; Easterling et al. 2007; Issaka et al. 2016). However, climate resilient agriculture also needs to promote coordination among stakeholders, local institutions and financing organizations to improve crop productivity (Lipper et al. 2014; Rai et al. 2018).

The detailed understanding of physiological phenomena, molecular mechanisms and genetics allows plant scientist to develop varieties that have adaptive traits and are able cope with climatic variations. Next generation breeding depends on the accessibility to plant germplasm collections, big data management skills, biotechnological interventions and molecular breeding through efficient high-throughput technologies. It permits scientific community to exploit suitable ideotypes to meet the breeding demands and also to search for superior alleles/haplotypes with potential use in next generation breeding programs (Taranto et al. 2018). Furthermore, recent advances in OMICS approaches, cisgenesis, genome editing and *in vitro* regeneration systems permit the development of second-generation biotechnology products (Cardi 2016; Cardi and Stewart 2016; Rinaldo and Ayliffe 2015), that may be crucial for sustainable agriculture in changing climate. Genome editing opened new horizons of in biology. Certainly, it unlocks innovative opportunities for the precise and robust genome modification to develop plants resistant against pests, diseases, and abiotic stresses (Osakabe et al. 2016; Courtier-Orgogozo et al. 2017; Appiano et al. 2015).

In short, the world population is projected to touch the figure of 9 billion by 2030 and it is inevitable to counter climatic challenges to satisfy forthcoming food requirements. For this purpose, we need to develop biotech crops resilient to adverse environmental conditions (Husaini and Tuteja 2012). Molecular plant breeding and other biotechnological approaches including genetic engineering and genome editing need to be integrated with conventional breeding for the development of climate resilient crops.

14.2 Impact of Climate Change on Agriculture and Food Security

The effects of climate change on agriculture are projected to increase over time (OECD 2014). The environmental factors like temperature extremes, heavy floods, recurrent droughts, and increasing salinity have already been affecting crop productivity. Adaptation to the climatic change is possible by decreasing the vulnerability of natural systems (IPCC 2014; Kelin 2014). In developing world, climate change is the main driver of food security and mainly affects the production of agriculture and other components of the food system (Wheeler and Braun 2013). Lower income countries are suffering greatly, such as, in arid regions, Africa and sub-humid South Asia. These regions are relying in sustenance agriculture and are not technically/financially sound to deal with the negative impacts of climate change (Droogers and Aerts 2005). Many African countries are already facing food shortages due to prolonged droughts. A recent survey by the International Water Management Institute (IWMI) has predicted that wheat productivity in South Asia is expected to decrease upto 50% by 2050. This amount is almost equal to 7% of the world crop production, hence the problem of food insecurity will be increased (Fraiture et al. 2007).

World's most hungry population constitute South Asia and Sub-Saharan Africa (Vermeulen et al. 2012). These are the most susceptible regions to climatic change (Bandara and Cai 2014). Pakistan is amongst the list of few countries which are inhabiting about 65% population of the world and suffering from the food insecurity problem. Situation in many Asian and African countries is predicted to become the worst as these nations are unable to take useful steps to cope this issue. Moreover, they are also incapable to reach the millennium development goals (MDG) and zero hunger (FAO 2015). Global population has reached 7.7 billion in 2019 and further estimated to reach about 9 billion by 2030 (Husaini and Tuteja 2012). It is more challenging task to supply nutrient-rich food to such a huge population. The unchecked population growth supported by increasing food prices and global food insecurity has resulted in the global food supply failure (Fischer et al. 2015). In order to meet the current challenge, it is estimated that 1.1–1.3% per year increase in yield of major crops is inevitable (Buchanan et al. 2015). Only in India, the population is expected reach 1.6 billion by 2050, therefore, 400 million tonnes of food will be needed to feed the estimated population in 2050. Sustainable food productivity by using same resources and land is necessary, nevertheless, impact of predicted global climate change may alter many components of the future crop production environment. In April 2009, the European Commission's Directorate General for Agriculture published a working document on "Adaption to Climate Change: the Challenge for European Agriculture and Rural Areas," outlined that high water-scarce areas are projected to increase from 19% to 35% by 2070. It has suggested a significant variation in the quality as well as availability of water at that time (Husaini and Tuteja 2013). Similarly, the Peterson Institute states that agricultural productivity in non-developed states will further decrease around 10% to 25% as global warming will reduce the capacity of agriculture system (Cline 2007).

Concentration of atmospheric carbon dioxide (CO_2), elevated temperatures, higher tropospheric ozone (O_3) levels, frequent droughts and intense precipitations may lead to severe flooding. Climate change may also cause water logging, land degradation, soil salinity and sodicity in vulnerable regions of the world. Agricultural pest and pathogens may also change their geographic distribution with the change in rainfall severity, concentrations and increasing temperature (Abberton et al. 2016).

Greenhouse gases such as methane (CH4), carbon dioxide (CO2), hydrofluorocarbons (HFCs), nitrous oxide and Sulphur hexaoxide (SF6) cause warm environment by reflecting radiations in the atmosphere, thereof, their increased concentration over longer periods of time leads to the global climate changes. Agricultural practices like over grazing, deforestation and synthetic fertilizer contribute 25% in emission of above mentioned greenhouses gasses in the atmosphere. Mitigation of climate change is possible by decreasing greenhouse gasses concentration, limiting gas emission sources and increasing beneficial crops for food security (Tesfahun 2018).

Incidence of drought in climatic change is the major problem for agriculture context. For this intention, agricultural research institutes and corporations are predominantly interested in the development of drought-resistant traits in agricultural crops because land area available for farming being reduced due to many reasons like rising temperatures and desertification.

The "International Institute for Applied System Analysis" (IIASA) reported that irrigation requirements at global and regional level may highly affect with the changes in climatic conditions and socioeconomic impacts. It is estimated that irrigation requirements may increase up to 45% by 2080 and overall 20% water withdrawals may rise even after upgradation of irrigation systems (Ali et al. 2017).

Sustainable Development Goals (SDGs) have been implemented globally in 2015 by many Nations, specifically to eradicate hunger, poverty and malnutrition by 2030. In December 2015, Paris Agreement was implemented by195 Nations to highlight linkages among impacts of climate change, safeguarding food security and ending hunger. Climatic Change Agreement of pairs also emphasize to restrict temperature below 2 °C and adaptation measures would be obligatory even for developing nations.

Biotechnology is a reliable solution to alleviate climatic change using strategies like carbon sequestration, energy efficient farming and reduction in the use of synthetic fertilizer. Transgenic crops have a potential and modest contribution in foremost problems faced by global society including self-sufficiency in food, production of nutritious foods, poverty alleviation, sustainability, hunger eradication and mitigation of global warming (Tesfahun 2018).

14.3 Impact of Climate Change on Crop Productivity: Pakistan's Perspective

It is estimated that climatic changes remarkably affect the agriculture productivity over the next hundred years and increasing climatic change is documented as a global long-lasting implication. The "World Bank's South Asia Climate Change Strategy" marked that climate change will affect more to the poorest people in these regions due to unfavorable geographic distribution, limited assets and greater dependency of income on climate sensitive sources. Highly frequent extreme climatic events are directly affecting poor farmers in the Asian regions such as Pakistan and India in recent years (Mendelson and Dinar 1999). It is affecting 2.5 billion poor peoples who are incompletely or totally reliant on agriculture. Climate change often affects different agriculture crops and regions differently. For instance, maize yield decreased by 3.8% between 1980 and 2010 globally. In Europe, heat waves cause yield reduction of maize in North Italy about 36% in 2003. In Central Asia 2009/2010, heat waves caused yield reduction of wheat. India and Bangladesh are dynamic contributors of world rice production and it is predicted that flooding/salinity will cause major threat to rice productivity in these areas (Banga and Kang 2014).

The "Global Climate Risk Index" (GCRI) ranked Pakistan as 21st in terms of exposure to alarming climatic factors from the period of 1993–2012 and according to world bank, Pakistan is 12th most extremely exposed country against climate change. Pakistan was ranked according to climatic change vulnerability and stood at 29th in vulnerable nations form 2009–2010. The "Global Climate Change Vulnerability Index" (CCVI) ranked 16th from 2010 to 2011. Pakistan faced main climatic events such as severe floods from 2010 to 2014 and droughts from 1999 to 2003 (Ali et al. 2017).

In Pakistan agricultural sector contributes 42.3% of livelihood to rural inhabitants and also 19.8% contributor of gross domestic product (GDP). Hence, food security and poverty reduction are the prime objective of the agricultural sector. Pakistan's major food crop are wheat, rice, maize, and sugarcane, which contributed about 32% in value addition over the period 2011–2012. In Pakistan wheat crop has been one of the most important staple foods since 1960s, major contributor to Pakistan GDP, self-sufficient production, widespread use in daily food and cheaper source to feed animals. Wheat sowing season is November in Pakistan and about its cultivation yield is about 2657 kg by using 9045 thousand hectares of land (Hussain et al. 2011). During the period from 2013 to 2015 a decrease of 1.9% was detected in wheat productivity from 25.979 million tonnes to 25.478 million tonnes. The major causes in productivity reduction were irregular rainfall and prolonged winter season. This year (2019) there was a vast attack of rust on wheat which is also thought to be due to irregular rainfall and delays in temperature rise (personal communication). Second major staple food and export item is Rice. Pakistan earned US$1.53 billion by the exporting it in 2014–15. There was a 3% recorded increase in the growth of rice over the period of 2013–2015 (GOP 2014).

Maize is an important food crop because it is used as a raw material in many industrial and domestic products. Maize production decreased upto 5% during the period of 2013–2015. This year there was a huge decrease in maize production due to high temperature during pollination days of maize in Punjab (personal communicaton). Sugarcane is also an important cash crop which earned US$171.78 million of valuable foreign exchange in 2014–2015 in Pakistan. But productivity of sugarcane decreased by 67.5 million to 62.5 million during 2014–2015 due to low availability of irrigation water (GOP 2016).

In Pakistan prevalence of freezing cold winters and dry hot summers is increasing. Pakistan's geographic characteristics are divergent such as it has high mountains (north, north-west, center and south-west), plateaus, deserts, plains and lengthy coastline. Every geographic location of Pakistan is characterized by different environmental/climatic conditions such as very cold, very hot and some remains moderate whole the year. Additionally, atmosphere dryness affects leaf potential by controlling stomata and extremely threaten to plant dry matter productivity (Amin et al. 2014). Plant growth is highly influenced by sunshine due to its effect on photosynthesis process, plant development, healthy growth, life cycle completion and food preparation mostly. Additionally, extreme sunshine and temperature cause negative effect to plants growth/development. Hence, climatic conditions are expected to cause various significant influences on crop yield. As mentioned earlier high/intense temperature affects photosynthesis including photosystem I, photosystem II and RuBisCO function. Contrarily, extreme low temperature cause chilling and injure to plants. Increase and decrease in temperature affect cropping seasons, irrigation patterns, evapotranspiration and heat stress on plants (Bhandari and Nayyar 2014). Intensive rainfall causes serious problems to farmers in monsoon season. It affects agriculture soil, causing soil erosion and soil surface washing. Similarly, humidity plays critical role in plant yield such as plant balanced growth needs adequate humidity. Low humidity or high humidity is not favorable for leaves growth, photosynthesis, disease occurrence, pollination and crops yield. With the change of crop duration seasons, its cultivation and crop sowing time modifications may help to reduce climatic threats (Ali and Erenstein 2017) . In Pakistan vulnerability index of climatic change is extraordinary as related to other countries around the world. Recently, Pakistan has faced climate changes including high temperature, precipitation variations, shifts in weather, severe floods and earthquakes, therefore, adaptations are highly needed for new climatic changes (Yousuf et al. 2014).

In Pakistan, canal water helps to irrigate about 6.34 Mha cultivated land, tube wells and supplementary sources help to irrigate cultivated land about 12.52 Mha out of total cultivated land 22.45 Mha. Therefore, 3.59 Mha remained unirrigated due to shortage of water supply (GOP 2018). Presently, water available for cultivated area of wheat is about 26 million acre feet, and the available amount of water is less as compare to required amount by 28.6% (Nelson et al. 2009). The IPCC 4th report proposed that in South Asia yield of crops would be decrease from 2001 to 2050 by 1820 m^3 to 1140 m^3. Additionally, drop in gross water/capita availability would also be predicted. The water supply is alarm in most country parts and it is projected that the unavailability of water would increase sharply in near future to agriculture sector. Climate models predicted that rainfall will increase during the summer period (Faruque and Kabir 2016). Moreover, Glaciers of Himalaya are melting quickly and many will vanish by 2035 (Misra 2014).

Agriculture sector has faced 3 huge floods in Pakistan and cause overwhelming effects to whole economy of Pakistan specially agriculture sector since 2010. The major floods faced by Pakistan due to climatic change are of the year of 2013, 2011 and 2010. Along with floods Pakistan also faced severe droughts of 1999–2003 and cyclones in 2008 to the main city of Northern Pakistan. An overwhelming flood happened before the reaping season of the major crops including wheat, rice, sugarcane, maize and vegetables, causes an estimated loss in productivity of these major crops about 13.3 million tons. In 2011 flood causes estimated damage of US$3.7 billion in Pakistan (Ali et al. 2017). The extreme damage in agriculture sector including livestock and fisheries. People effected by rains and sever floods were estimated about 2.5 million in September 2014. Moreover, one million acre agriculture land, 250,000 farmers and 129,880 houses were affected. The estimated total cost for recovery and rehabilitation was about US$2.7 billion. These statistics show that sector most affected by floods in Pakistan was agriculture (GOP 2018).

There is an urgent need for climatic change adaption, which includes several measures. For instance, with the change in 11 African countries temperature, farmers start to use alternative crop varieties and conservation of water etc. Secondly, with change in the precipitation, farmers shifted planting dates. Similarly, strategies usually opted by South African and Ethiopian farmers include diverse crop varieties plantation, cultivating more trees, soil conservation and changes in sowing/irrigation dates of major crops (Bryan et al. 2009).

14.4 Broadening the Genetic Resources and Genomics Based Breeding

Crop breeding to produce climate resilinet crops is not a new strategy. Farmers uses those field crops which are most suitable to the environment. Influence of extreme waves of heat has been investigated in maize, wheat, soybean and rice (Rejeb et al. 2014). Breeding crops is a slow and laborious process for environmental stresses to enhance crop varieties, as the effects of different stresses on crop varieties are complex and variable specifically when crop varieties are exposed to numerous stresses simultaneously. Increase in temperature and moisture produces germination propagules and accelerates the growth rates of pathogen. It is known that rise of 1 °C temperature determines a reduction in produce ranging 7.4% in maize crop to 3.1% in soybean (Zhao et al. 2017).

Diseases in wheat like Fusarium head blight (FHB) are increasing in United Kingdom, China and other European Union (EU) countries which is thought to be realtede with the fluctuations in weather conditions. Several induced biotic and abiotic cross tolerance positive examples are also available, which causes increased resistance in plants due to plant breeding (Wang et al. 2014).

Overwhelming climatic abiotic stress control in agriculture crops using breeding programs has been confirmed very effective to increase food productivity and alleviating climatic effects. To response climatic change adaption, deep understanding of physiological, genetic and molecular mechanism is required, and identification of climatic effect resilient traits are the major objective for next generation breeding (NGB). While NGB mainly depends on plant breeding populations, collection of germplasm, high-throughput advanced technologies, management tools and downstream molecular breeding activities. It provides scientists to develop one or more ideotypes in short time span to fulfil breeding requirements and also for the discovery of superior alleles/haplotypes for breeding programs (Taranto et al. 2018).

14.4.1 Climate Smart Molecular Plant Breeding

The "Intergovernmental Panel on Climate Change" (IPCC) published the "Second Assessment Report" on the effect of environmental variability on the feasible advancement of the general public. This report has established the frameworks for accomplishing the universal understanding connected to the "United Nations Framework Convention on Climate Change" (Kyoto Protocol) (Breidenich et al. 1998). The "IPCC" reported numerous aspects related to evaluation, adjustment and reliefs of environmental variations with respect to climatic and socioeconomic facets. Breeding crops for abiotic stress resilience is obliged by the intricate idea of abiotic stress resistance (timing, intensity, duration frequency) and along these lines its evaluation and repeatability. In plant breeding undesirable traits of genes along with desirable genes can be transferred, which may cause barrier for favorable allele transfer. This pattern mirrors the ongoing history of technological advancement and methodological developments in crop plant breeding. QTL mapping, actually, is the most established technique utilized in plant breeding to recognize hereditary variations that impact the extent of quantifiable traits (Dhingani et al. 2015*)*. On the other hand, genome editing techniques have been introduced more recently to support plant breeding. All of the new cutting-edge advance techniques proved as a helping hand in the recent years, predominantly after 2013. Information concentrated on crop breeding methodologies and translational genomics will add to create atmosphere confirmation, genetically improved seed-embedded technologies which in collaboration with sustainable agricultural ecosystem management system, eco-efficient crop husbandry and sound postharvest handling will help encouraging the world in this time of climate change (Abberton et al. 2016).

14.4.2 QTL Mapping and Marker-Assisted Selection

Population mapping are extensively used to examine the relation among variation in trait and DNA polymorphisms. High-resolution trait mapping suggests suitable genetic material selection in crops, to develop several germplasm resources for breeding climate resilient plants. The accuracy/resolution of quantitative trait loci (QTLs) and mapping may be influenced by recombination rate, population size, recombination frequency and trait heritability (Cockram and Mackay 2018).

Genetic basis of complex traits could be dissected by using two population types, first one is Association Mapping Populations and second one is family based mapping population. Because, both Linkage disequilibrium (LD) decay and recombination rate greatly differ among these two (Xu et al. 2017).

Family based mapping population includes both Bi parental and Multi parental mapping populations. Bi parental mapping populations (BPP) is frequently originate after the cross among two conflicting individuals different for one or more target characters and its variation depend on narrow genetic base, are typically used for quantitative trait loci mapping. Whereas, Multi parental mapping populations (MPPs) are appropriate resources for complex trait genetic basis due to its greater phenotypic diversity and higher recombination events (Mackay and Powell 2007).

Association mapping population developed through valuable natural genetic sources by gathering hundreds of dissimilar individuals amongst old and elite land-races, cultivars and wild relatives. Individuals of these populations are mostly include from diverse parts of world, high allelic richness and widely diverse in characterization for high-resolution QTL mapping (Sacco et al. 2015).

Nested Association Mapping populations is the combination of Bi parental mapping population and the Associated mapping population, to develop a single mapping population to improve agronomic traits for greater precision of QTL mapping (Yu et al. 2008).

Associated molecular markers are identified by using QTLs and marker-assisted backcrossing (MABC) further used to introduce candidate genes for example bacterial blight and blast resistance in rice (Joseph et al. 2004).

For QTL different methods have been established and QTL mapping software have been applied (Sehgal et al. 2016). The QTL mapping resolution can also be improved by joining linkage disequilibrium maps and linkage. Recently molecular classification of QTLs along with DNA polymorphism identified imperative traits, such as wheat FHB resistance and barley resistance to drought (Gupta et al. 2017).

14.4.3 Genome-Wide Association Studies

Genome-wide association study involves investigation of marker-trait associations on the basis of large DNA nucleotide variability within association mapping populations. Additionally, each individual phenotypic data is required from the population to score important genotype–phenotype associations. Different tools and methods are established for association analysis such as GAPIT and GEMMA (Hayes 2013).

In several crops genetic based resistant mechanisms/traits and their predictive factors related with climatic change have been identified on the basis of GWAS. For the selection of functional marker association, particular InDels or SNPs have been used in breeding programs mostly in cereals and leguminous to develop new resistant crops. SNPs associated markers have been identified in sorghum by using GWAS against heat stress at the vegetative growth stage at field situations (Mitterbauer et al. 2017).

SNPs involved in leaf blotching and leaf firing were positioned in target genes help to cope heat stress or heat tolerance responses such as transcription factors, kinases, heat-shock proteins and phospholipases. In chickpea, collection of germplasm was used to detect important marker-trait associations SNPs for developing superior varieties to enhance heat tolerance, drought tolerance and yield (Li et al. 2018).

Genomic selection (GS) is a powerful technique to facilitate the superior genome selection, reduce the cost of breeding line development and accelerate the breeding cycle. First of all, a training population (TP) is collected to genotype and phenotype for searching traits of interest and obtained data combined with pedigree knowledge to construct genome selection prediction model, which link genome-wide marker data to phenotypes. At the end, obtained models are used on different groups of individuals whose genotype identified previously but unidentified phenotype to get data on their genomic estimated breeding value (GEBV). International Maize and Wheat Improvement Center (CIMMYT) provide information about thousands of wheat lines phenotypic data related to heat and drought stress for grain yield by analyzing in different climates. It was obvious that GS increase prediction/selection precision in wheat, together with phenotyping and high-throughput genotyping approaches (Crain et al. 2018).

Advanced next generation DNA sequencing (NGS) technology is the major driver for the present genomic revolution. It provides benefits for diverse crop genome sequencing, genomic-assisted breeding and also provide information about diverse genome association with agronomic traits. Genomics in combine with phenotypic information also provide knowledge for rapid selection and advanced strategies to breed crops against climatic changes (Gepts 2004).

14.4.4 Mutation Breeding

Mutation breeding arise in the last era aiming to develop artificial genetic variability. Since the 1930, physical and chemical agents are used in about 170 different crop species to induce genetic mutations such as to develop novel alleles, genetic diversity enhancement and development of mutant varieties. Basically mutation is the heritable modification to the genetic material and very important for evolution/domestication of crops. Physical and chemical agents along with the innovation in X-rays and different types of radiations in twentieth century open the way to modify the genetic material permanently. For crop improvement induced mutation prove an established strategy because with the use of this technology about 3200 officially improved crop/ornamental verities have been developed all over the world. In induced mutations probability of success chances are less, therefore, to enhance success rate more putative mutation events are carried out by scientists to select final mutants screening but this strategy is expensive and time consuming.

Biotechnology applications are used to overcome induced mutation drawback and to enhance the efficacy levels for creating huge populations. For this instance, “Targeted Induced Local Lesions in Genomes (TILLING)” reverse genetic high throughput technique based on chemical induced mutagenesis is used to effective screening mutations in huge populations such as loss of function and gain of function alleles associated with phenotypes (Kurowska et al. 2011). In certain, new heat shock protein (*Hsp26* gene) family allelic variants are identified to control thermal tolerance and heat stress in wheat and mutants of barley were created to detail study of nucleotide variation in improved response to *ABA1* gene (era1 gene), which regulate drought tolerance differently in wheat and soybean using TILLING. An alternate strategy is deletion TILLING (De-TILLING) which absolutely allows to detect knock-out mutations (Rogers et al. 2009).

EcoTILLING is a strategy to identify individual natural mutation and very essential tool to discover allelic variants against climatic variations such as biotic and abiotic adaptations. Molecular biology techniques are also used to improve the efficacy of mutation induction, for example, doubled haploid to achieve rapid homozygosity of genome mutated parts in time, cost and space effective manners. The other effective/important uses of cell biology techniques are conservation of germplasm, hybridization barrier removal and disease free planting materials multiplication to crop improvement. (Taranto et al. 2018).

14.5 Genetic Modification (GM) of Crops for Climate Resilience

Plant biotechnology includes the viable applications including biological organisms, or their subcellular segments in the agricultural farming. The systems as of now being used incorporate convectional breeding, tissue culture, and molecular breeding (MB) and Genetic engineering. Techniques of genetic modification provides access to an importantly improved gene diversity for the development of crop plant varieties with these improved traits. Comprehensively, the traits which were important for adoption of plants to change in climate include drought tolerance, salinity tolerance, heat stress tolerance, efficient water usage, early vigor, efficient nitrogen use, water logging, frost tolerance, disease resistance and pest control to activate germination of seeds or flowering. Genetic modification techniques are promising path for alleviating negative impacts of environmental change by decreasing greenhouse gases, biofuel use, carbon sequestration, less use of fertilizers and tolerance of abiotic/abiotic stresses (Hsieh et al. 2004; Barrows et al. 2014).

Climate-resilient crops which were genetically engineered to adapt impacts of climate change on crop yield and agriculture plants. In previous decades, with the introduction of “Golden Rice” made using present day genetic engineering technology, was a noteworthy development. It includes the transformation of genes which were essential for carotenoids accumulation (Precursor of vitamin-A) in rice endosperm, which does not comprise any pro-vitamin A due to unavailability of coding gene in rice genome. It has been confirmed that in human’s *β*-carotene availability from “Golden Rice” is proficiently converted to vitamin-A and about 140 g of *β*-carotene for a child’s recommended daily allowance (RDA) are provided by rice (Ye et al. 2000; Raney and Pingali 2007).

United States Environmental Protection Agency (EPA) and Food Inspection Agency (CFIA) currently approved more stacked genetically modified maize name as “SmartStax™” in which 8 cry genes are stacked such as *Cry2Ab, Cry1A.105, Cry1F, Cry3Bb1, Cry34, Cry35Ab1, Cp4* and *bar*. It is considered to offer the most inclusive insect pest and additionally herbicide tolerance in transgenic *Bt* maize (ISAAA 2017).

The “African Agriculture Technology Foundation” (AATF) conduct several projects with the partnership at international level for the development of drought tolerant maize verities in Africa by using biotechnology advanced techniques at international level. Recently, IRRI has developed submergence tolerant rice by introducing *SUB 1A* gene to protect rice crop from water damage and rice give good production under water even after 2 weeks under water. Now, scientists are trying to develop C4 rice varities to increase yield up to 50% as compared to the available rice varities (Stone 2008).

In agricultural soils cumulative carbon sequestration can be attained via exploiting the carbon amount carried by the soil and increasing carbon dioxide amount retention in the soil. Approaches applied to attain this goal are the development of new varities with the help of biotechnology techniques which also increase plant photosynthesis rate, lignin content quality, deep roots of plant and nutrient use efficiency and water usage efficacy (Ruan et al. 2012).

Nitrogen fertilizers use in agriculture accounts for 33% of greenhouse gases emissions. Nitrous oxide causes about 296 times more global warming as compare to CO_2 and can stay in atmosphere more than 100 years. GM Canola and rice that use N_2 more proficiently are established to need less fertilizer and thus decrease the N_2-fertilizer amount which were lost into the soil, air and watercourses. Nitrogen use efficiency enhancement in crops may help to decrease fertilizer applications, ultimately cause to reduce greenhouse gases emission in the environment. Because, agriculture practices and fertilizer applications account more the 50% in greenhouse gas emission in US (Desai and Harvey 2017).

Recently, in Arabidopsis a “Thermometer gene” has been discovered that enables plants to not only feel rise in temperature, but also help in proper response. The scientists reported that the important proteins for plant’s ability to sense temperature is a specific histone protein (*H2A.Z*) that tightly binds the DNA at lower temperatures and drop off from DNA at high temperature ultimately preventing gene expression (Kumar and Wigge 2010).

Our long-term scientific strategy must be to develop technologies for producing “weather-proof” genetically engineered biotech agriculture crops. Many crop plant species Genome sequences are accessible now such as maize, rice, sorghum, soybean and Poplar (*Populus trichocarpa*) (Tuskan et al. 2006). Transcription factors, ROS scavenger proteins and protein kinases encoded by transgene are the most appropriate as these confer an adaptive benefit to transgenic with respect to many stresses. One significant way of achieving tolerance to stress conditions is to overexpress genes for transcription factors that control numerous biochemical paths such as “Ethylene Responsive Element Binding Proteins” (*EREBP*), “Dehydration Responsive Element Binding Proteins” (*DREBs*), “C-repeat Binding Factors” (*CBFs*) and “Mitogen Activated Protein Kinase” (*MAPKs*) for the development of climate resilient agriculture (Husaini and Tuteja 2013).

Development of GM crop plants usually depends on *in vivo* plant regeneration and well established tissue culture for somaclonal induced genetic variation in plants for better changes. Recent development in transformation technology minimize/bypass tissue culture step and also reduce somaclonal variation frequency during tissue culturing. Furthermore, there is no barrier to transfer or instruction of beneficial genes or alleles across diverse species from the plant or animal kingdoms with the use of genetic engineering applications.

14.6 Genome Editing (GE) of Crops for Climate Resilience

Recent developments in biotechnology involving genomics based knowledge and availability of rapid gene information as well as enhanced knowledge about *in vitro* tissue culture techniques allow the use of second generation advance biotechnology applications based on genome editing and *cis*-genesis. These advanced technologies help for the production of diverse range of value-added novel crop products to mitigate future challenges related to sustainability of agriculture. Genome editing (GE) technology opens a novel prospects for the specific modifications in agriculture crops for disease protection, pest control, defense against biotic/abiotic stresses, faster crop breeding and at the end maximum crop yield with less production cost (Appiano et al. 2015; Courtier-Orgogozo et al. 2017).

Cutting edge genome editing technique is listed under the major group of “New Plant Breeding Techniques” (NPBT) and further classified as “Oligonucleotide

Directed mutagenesis" (ODM) and "Site Directed Nucleases" (SDNs), these allow transfer of gene, target sit mutations and for gene expression control (Cardi et al. 2017).

14.6.1 Oligonucleotide-Directed Mutagenesis

In the "Oligonucleotide Directed Mutagenesis" DNA fragment of about 20–100 nucleotides are chemically synthesized and transfer to the plant genome at target site using particle bombardment or polyethylene glycol (PEG) mediated gene transformation method, however, induced mutation efficiency is very low approximately 0.05% at the target site using this method (Aubert and Kesteloot 1986).

14.6.2 Site-Directed Nucleases

Site-directed nucleases are basically enzymes which binds to the small DNA sequence at specific target site (9–40 nucleotides). They work *in suit* to conduct different enzymatic reactions by introducing double strand break such as acetylation reactions, methylation/demethylation reactions and deamination reactions. These biological reactions cause in alterations of biological activities by gene silencing or genome editing (Puchta 2017). Double Strand Break (DSB) of site directed nucleases biochemical reaction is the most prominent biochemical reaction in the living cells and DSB repaired with the help of "Homologous recombination" (HR) or by "Non-Homologous End Joining" (NHEJ). Homologous recombination is a repair mechanism used for the insertion of large DNA at target site and also for non-random mutation. On the other hand, non-homologous end joining is used to introduce random insertion at target site to knock-out gene or knock down gene expression (Aubert and Kesteloot 1986).

Site directed nuclease are further classified as "Zinc Finger Nucleases" (*ZFNs*), "Clustered Regularly Interspaced Short Palindromic Repeats" (*CRISPR*) and "Transcription Activator-Like Effector Nucleases" (TALENs).

CRISPR/Cas-9 is another genome editing tool to add, change and remove genetic information present in DNA and RNA. *CRISPR/Cas*-9 technique originally from defense system of bacteria, can further be used in variois types of cell in any organism including plants, micro-organisms, humans and animals (Barrangou and Doudna 2016). Most recently, Nekrasov et al. implied *CRISPR/Cas*-9 technique successfully in tomato plants to induce a loss-of-functional mutation susceptibility gene *SlMLO1* of the powdery mildew (Zheng et al. 2016). Applications related to abiotic stresses are still limited to model plant Arabidopsis, recently, auspicious results in soybean and cocoa have been reported against drought/salt tolerance (*Drb2a/Drb2b* genes) with the use of this genome editing technology (Farrell et al. 2018).

TALEN was used successfully for the first time by modifying promotor region of *OsSWEET14* gene in rice crop, which cause susceptibility towards bacterial blight disease in rice. Due to modification in the promotor region "effector binding element" does not bind with the promotor and cause bacterial blight resistant in the crop. TALEN was also used successfully to edit three Homoalleles of the susceptible genes *MLO* (Mycoplasma Like organism) to introduce resistance against powdery mildew disease in the bread wheat (Wang et al. 2014).

14.7 Recent Breakthroughs in Climate Resilient Agriculture

Molecular breeding, genetic engineering and genome editing integrated approaches proposed new prospects for developing improved climatic resilience or stress resistance by using whole genome sequences, complete genetics, physical maps and functional genomics tools in important crops like wheat, sorghum, soybean, rice, potatoes, maize, orange and tomatoes (Manavalan et al. 2009).

Monsanto has developed drought resistant maize named as 'MON 87460' or 'Drought Guard' in the perspective of intense droughts in United States. These maize varieties are highly adaptive or withstand drought situations and increase yields/productivity. In this framework, maize community conducted numerous significant projects including "Drought Tolerant Maize for Africa" (DTMA), "Water Efficient Maize in Africa" (WEMA) and "Improved Maize for African Soils" (IMAS) (Varshney et al. 2011). Drought tolerant maize crop produces 20–50% high yields in drought conditions as compare to other varieties. Salt tolerance has also been improved by overexpression of 40 transcription factors out of 1500 screened transcription factors in *Arabidopsis thaliana*. The maize transgenic lines were produced that were more tolerate to drought due to improved stomatal conductance, increased photosynthesis, high chlorophyll content and ultimately high productivity of grains (Nelson et al. 2007).

In rice structural design of roots have been improved by identifying DEEPER ROOTING 1 (*DRO1*) locus bringing about better drought tolerance, higher crop yield and improved nitrogen acquisition due to change in vertical root directions and deeper roots (Arai-Sanoh et al. 2014). Monsanto researchers have also developed bacterial cold shock proteins (*Csps*) that can provide enhanced stress adaptation to several plant species. There are other examples of transgenic rice and maize lines for production maintenance and growth development during insufficient water supply by introducing *CspB* (Castiglioni et al. 2008).

Recently, in Tobacco (*Nicotiana tabacum* L.) an Aquaporin coding gene *NtAQP1* was identified which is reported to protect transgenic plants against salinity stress, shoot/root hydraulic failure prevention by endowing better water use efficiency in salt tolerant genetically modified tomato (*Solanum lycopersicum*) (Sinclair et al. 2004). Similarly, genetic engineering technique is used to improve Rhizobium-based nitrogen fixation properties in genetically modified/transgenic Canola. It exhibited improved nitrogen fertilizer uptake and reduced nitrogen lost into atmosphere, leaching into soil and removal through water.

Biotechnology have proved to decrease greenhouse gas emissions substantially. It was due to less use of fossil fuel and retention of soil carbon by virtue of less tillage. In 2012 it was reported "equivalent to removing 27 billion kg of carbon dioxide from the atmosphere or equal to removing 11.9 million cars from the road for one year" (Zahran 2001; Tesfahun 2018).

Carbon (C) sequestration is defined as the uptake of Carbon (C) substances predominantly carbon dioxide CO_2 from atmosphere. Genetically modified plants help to sequester millions of tons atmospheric carbon dioxide, for example in USA and Argentina herbicide resistant Roundup Ready™ soybean crop proved to sequester about 63,859 million tonns carbon dioxide (CO_2) (Brimner et al. 2005).

Saline conditions are increasing very rapidly in arable soils, which has made up to 30% of arable land unavailable for cultivation within 25 years and it is predicted to reach about 50% by 2050 (Valliyodan and Nguyen 2006). To cope with this situation several genetically modified plants have been developed for better performance in abiotic stress like high/low temperatures, hypoxia, salinity, atmospheric pollutants and hyper osmosis to achieve tolerance (Liu et al. 2007).

Recently developments in technology permit studies of climatic stress conditions/responses using the OMICS data involving transcriptomes, proteomes and metabolomes at a molecular level worldwide for example *SNAC1* gene (*NAC* transcription factor) was recognized in rice through microarray experiments in stress conditions through which drought and salt tolerance of rice improved. Knowledge of whole genome sequencing in crop plants (125,000 genes in single wheat chromosomes) opens the way to identify complex traits involved in yield, grain quality, disease resistance and climatic stresses. With the advent of new sequence technology it is now time to use digital biology or next generation breeding programs for better improvements in genomics, transcriptomics, phonemics and bioinformatics (Hu et al. 2006).

14.8 The Consumer's Aptitude Towards Biotech Crops

Genetically engineered and genetically modified foods are defined by World Health Organization (WHO) as 'the foods derived from different organisms, whose DNA/genetic material has been improved with the introduction of genetic materials which is not present naturally'. Genetically modified crops are producing promising results with the introduction of novel agronomic traits such as improved salt/drought tolerance, high temperature tolerance and pest resistance. However, such valuable crops have not reached to the poor farmers due to tremendously high cost of governing compliance. Nevertheless, the most important consumer-oriented GM crop "Golden Rice" has been facing bio-politics issues causing needless delays in commercialization (Makinde et al. 2009).

Besides political, ethical and socioeconomic apprehensions about new biotech crops biosafety, biopiracy and bio-advocacy related issues such as unavailability of biosafety regulation, non-compliance of biosafety regulation if available, bad compliance of intellectual property rights, negative cultural practices, customer's ignorance, fear of unknown and many other religious perceptions cause obstacles in the regular adoption of biotech crops in various countries. To mitigate all these current challenges in the acceptance of modern biotech biotechnology, governments should set up proper biosafety policies and legal framework before approval of transgenic crops. Scientific advocacy is required to help consumers as well as policymakers to understand the nature of benefits/harms of modern biotech crops (Stringer et al. 2009).

It is noteworthy that World's top scientific bodies like the "US National Academy of Sciences" (NAS), the "German Risk Assessment Agency", the "UK's Royal Society", the "New Zealand Royal Society", the "Canadian Royal Society", the "European Academy of Science" and "India's Seven Science Academies" have declared GM crops safe. World largest council named "International Council for Science in France" held a call to "National Academies of Sciences" including 150 scientific societies/organizations and issued a comprehensive report of GM crops/food on health and environmental risks. With final Council report decision "There is no evidence of any health hazard effects with the consumption of genetically modified food". Council further reported that "There is no evidence of any deleterious climatic/environmental effects due to the trait or species combination." Despite of all these verdicts on one hand and proving useful in restricting the application of toxic chemical insecticide and pesticides in combating insect/pests & diseases, transgenic crops have yet not received worldwide acceptance (Persley 2003). Genome editing is relatively a new field whose biosafety issues are still under debate.

Hence, policies should be strengthened to enhance consumer awareness, maintain research, support scientists work, analysis system and industry applications and networks of information dissemination. Other options for the development of climate resilient agriculture include improved management strategies, judicious land usage, development programs about climate change, improved irrigation infrastructure, storage infrastructure, efficient markets for products, financial services like insurance and agricultural inputs (Turvey 2001).

14.9 Conclusion

The field of biotechnology has contributed significantly towards climate change adaptation and mitigation through decreased discharge of GHGs, carbon sequestration, production of cleaner fuels, breeding of better-adapted crop varieties and reduced use of chemical fertilizers. These measures have helped to enhance agricultural productivity on one hand and protecting biodiversity and ecosystem on the other. Wise use of all modern biotechnological tools including genomics, genetic engineering and genome editing will help to counter climate-change related problems and thereby enhancing crop yields to feed ever-increasing human as well as animal population on earth. It will positively contribute towards food security and climate change adaptation and mitigation efforts.

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Chapter 15
Insect Pests of Cotton Crop and Management Under Climate Change Scenarios

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Abstract Insects comprise the largest group of animal kingdom and play vital role in providing various ecosystem services. Some of these tiny creatures serve as notorious and serious pests of crops including cotton. Cotton is an important fibre crop which being succulent, is observed to be attacked by various chewing and sucking insects. Due to anthropogenic activities, climate on the earth is being chaged since last century that leads to global warming. Under this situation of climate change, abiotic factors like temperature, humidity, rainfall and atmospheric gases (especially CO_2), and biotic factors like parasites, predators, competition are dominant factors that govern population dynamics and proliferation of insect pests of cotton. Insects being poikilothermic in nature have temperature of their bodies is approximately the same as that of the environment. Therefore, the developmental rates of their life stages are strongly dependent on temperature. So with the increase in temperature, almost all insects are affected to some degrees by changes in temperature due to global warming and there may be multiple effects upon insect life histories. These effects exert impact on crop

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_15

insect pests' populations in several complex ways like extension of geographical range, increased over-wintering, changes in population growth rate, increased number of generations, extension of developmental season, changes in interspecific interactions, changes in crop pest synchrony, increased risks of invasions by migrant pests, introduction of alternative hosts and over-wintering hosts. The various methods such as culturals, physicals, biologicals, botanicals, entomopathogenic fungi and synthetic chemicals are adopted by farmers and researchers at national and international level to control pest population. Among all above mentioned methods, the main emphasis in insect pest management in cotton crop is use of synthetic pesticieds. These are although cheap, effective and having faster action but have much side effects like environmental pollution and health hazards due to their penetration in food chain. Due to excessive and non-judicious use of these chemicals on high infestation of cotton pests, resistance and resurgence of these pests are now being recorded as more serious. Such situation leads in integration of all possible alternate measures like resistant cultivars, GMOs, genetic controls, use of biocontrol agents, use of biopesticides, use of insect pheromones and many others for effective control. So, effects of climate change on insect pests of cotton crop and management tectics in this scenario are being reviewed in this chapter that will provide a ready reference for policy makers and researchers to improve management practices of cotton pests in various geographical areas, in ecofriendly and efficient way.

Keywords Cotton · Chewing pests · Sucking pests · Integrated pest management · Abiotic factors · Biotic facors

15.1 Introduction

The history of cotton is as old as the Indus Valley Civilization. The first evidences regarding cotton cultivation were found from the era of Indus Civilization during 4th–5th millennia before Christ (Stein 1998). From Indian Subcontinent, cotton was spread to other countries of the world. The basic techniques of cotton spinning, dying, weaving and fabrication were developed by the habitants of Indus Valley which are still in use with modifications. The subcontinent the only place where skills for various uses of cotton are being employed since times immemorial. As cotton and cotton products got popular, Arabs traders started to export it to European countries like Italy and Spain in renaissance. Cotton was also reported to be used in England during fourteenth century AD, where people firstly did not use it for its personal purposes, but only for making wicks of candles.

Foods and Nutrition Encyclopedia stated the first use of cotton in areas now in USA and Mexican region was estimated to somewhere 8000 years ago. The local variety was identified as *Gossypium hirsutum* which is the best cotton known to world and now in twenty-first century 90% of the cotton land is under its cultivation. Wild cotton had been reported from Mexico, Australia and Africa (Schanz 1912).

Two species of cotton were adopted for commercial cultivation; one belongs to American origin that is *Gossypium hirsutum* and other belongs to subcontinent that is *Gossypium arboreum.* Both were known for longer and stronger fiber. In nineteenth century, cotton was the only crop popularized as the "King" and for the first time it became the backbone of southern American economy (Yafa 2004). For now, cotton is being cultivated in more than 75 countries.

Due to succulence and greenish in nature, cotton plant is attacked by diverse and vast range of insects *i.e.* a total of 145 pests including the mites have been reported to attack this crop.

15.2 Climate Change and Insect Pests

Anthropogenic climate change is a threat not only for human being but also for agricultural crops in general and for cotton in particular. With the increase in climate change, cotton has been affected badly. Adverse effects can be pooled-up by multiple reasons such as effect of increased abiotic stresses especially temperature on the beneficial fauna present in cotton crop, availability of complex strains of insect pests leading to failure by using insecticides, and affecting positively on secondary pests thus giving them the status of major pests. Even, it can have some negative impacts on major pests of today over varied geographical regions (Tripathi et al. 2016).

Cotton pests include the example of many species which has been thought to be affected by the climate change. It has been observed that occurrences and densities of various pests are increased and shifted to other and new areas, such as shifting of *Helicoverpa armigera* (Hub.) and *Maruca vitrata* (Fab.) to the other region on diversified crops like legumes (Sharma 2005, 2010). In USA (Brazil), *H. armigera* is known to be an invasive pest on crops and it happened just because of climate change (Czepak et al. 2013; Tay et al. 2013).

Here in below paragraphs, we brief generally the effects of major abiotic factors on life and biology of insect pests of cotton.

15.2.1 Atmospheric CO_2

The host plants which are grown under high concentrations of atmospheric CO_2, become less nutritious for insect pests due to change in phenology of host plant, ultimately reduce the developmental stages of insects. (Zvereva and Kozlov 2010). But it is not true always, and various insects behave differently in increasing concentrations of CO_2 due to climate change. For example, it shows a positive effect on the population of *Spodoptera litura* (Fab.) and now it is becoming a major pest and challenging the people for its management (Kranthi et al. 2009), and *Ceratovacuna lanigera* is now counted as a major pest in Maharashtra, India (Bade and Ghorpade 2009).

15.2.2 Temperature

Temperature affects growth and development of insects as these are endothermic and need high temperature for their growth and reproduction. Warmer temperature is favorable for insects. Life cycle of insects decreases during high temperature. If the temperature continues to grow in the same pattern, more insects will be will be among survivors in winters, consequently huge populations will here for coming spring (Sharma 2005). In such a scenario, behaviors of many insect species including pests will be altered, e.g. migratory behavior of *Helicoverpa* spp. will help them to search for new sites. Likewise, whiteflies' populations will also be increased as it is being affected mostly by temperature, rainfall and humidity (Pandher et al. 2011). In that situation, the life of beneficial fauna will be in danger (Sharma 2005).

15.2.3 Relative Humidity

Like temperature, humidity changes the behavior of insect pests, predators and parasitoids. During high humidity, fungus attacks more to various insect pests like thrips, jassid and aphid and resultantly help to suppress populations of these creatures. Many delicate insect pests like whitefly are washed away during heavy rainfall (Reiners and Petzoldt 2005).

15.3 Lepidopterous Pests

15.3.1 Pink Bollworm

Genus *Pectinophora* (Lepidoptera: Gelechiidae) has four species including; *P. gossypiella*, *P. endema*, *P. fusculella* and *P. scutigera* out of which Pink bollworm *Pectinophora gossypiella* (Saunders) commonly called as Pink Bollworm is a notorious pest of cotton. It is monophagous insect feeds only on cotton and widely distributed in all cotton growing areas of the world and causes severe damage and yield loss.

15.3.2 Distribution

P. gossypiella has been reported in India (1843) Hawaii (1901), East Africa (1904), Malaysia and Burma (1906), Egypt (1907), Australia (1911), Mexico (1911), Brazil (1913), Texas (1917), China (1918) and California (1965). This pest was transferred to West Indies and the Philippines through shipping (US Department of Agriculture, Animal and Plant Health Inspection Service, 1977). Now this pest found in all over the cotton growing areas of world.

15.3.2.1 Biology and Life Cycle

The eggs of the *P. gossypiella* are oval in shape with 0.2–0.3 mm wide and 0.4–0.6 mm long which have been laid under the bracts of bolls. In the early season, female lays eggs on sheltered places of plant axis or undersides of leaves, buds and flowers. The eggs hatch in 3–4 days. A single female can produce 200–400 eggs in entire her life. White color with brownish head larvae hatch from eggs, which afterwards change into pinkish color. Larvae bore into buds and bolls where they feed on inner material of bud and seeds in the bolls. Cotton bolls of 10–24 days old are most susceptible to *P. gossypiella*, resulting in shedding of fruits, seed loss and lint damage (Sarwar 2017). The four to sixth larval instars of this insect are found during their life cycle. However, under the cool dry conditions, larvae undergo diapause in double seeds.

15.3.3 Management

15.3.3.1 Cultural Control

Many cultural practices have been adopted in the early, late planting of crops because the hibernating larvae when emerged before planting, then they have no food supply. Beasley and Adams (1995) have suggested several cultural practices including the use of short duration varieties, crop rotations and other recommendations for harvesting and dealing with crop debris. Some other practices include land preparation, proper irrigation, follow the sowing date, control of unwanted plants (weeds), proper fertilizers and use of resistant varieties (El-Amin and Ahmed 1991). It has been reported that gin trash is a carrier of pests. Cotton ginning mills with adequate fans for expulsion of gin trash have fewer cotton pests than those mills without this equipment. Elimination of food supply for pink bollworm by cutting off irrigation early enough to stop production of green bolls may help in lowering the pest population. After harvest of cotton crop, immediately shred the plants because shredding destroys some larvae directly and promotes rapid drying of un-harvested bolls hence killing hiding ones. Winter irrigations can also help to reduce populations of hibernating larvae. The use of Bt cotton can help to prevent damage by *P. gossypiella* hence better yield. The larvae of this pest have been developed resistance against Bt cultivars in some regions. Therefore, the seed breeders must ensure that Cry toxins are present in the hybrids in homozygous form, instead of the segregating heterozygous form as in the current hybrids (Sarwar et al. 2013). Use of refuge crop (non-Bt with Bt) is better option to control resistance in this pest against Bt varieties.

15.3.3.2 Chemical Control

The chemical control is hindered by the PBW larvae being internal feeders, moreover, resistance to insecticides develops making it often more expensive than other methods. However, there is an extensive literature on chemical control is available. Application of Chlorantraniliprole at 50 ml/acre, Spinetoram 100–120 ml/acre, Spinosad 80 ml/100 l of water and Lambda-cyhalothrin 330 ml/100 l of water have been tested. These insecticides must be reapplied every 7–10 days to provide protection, and wear protective clothing during applications (Sarwar and Sattar 2016). Sanghi, et al. (2018) tested 6 different insecticides against the PBW and found that Triazophos + Deltamethrin provided 89.8% mortality during experiment, followed by Gamma cyhalothrin (79.1%), Spinetoram (73.4%), Deltamethrin (65.1%) and Triazophos (59.8%). However, Abd El- Mageed et al. (2007) recorded that Betacyfluthrin, Spinosad and Malathion induced the highest reduction of pink bollworm larvae, respectively. It has been recorded that higher concentration of insecticides provided promising results as compared to low doses (Sabry et al. 2014).

The high concentration of Triazophos provides higher mortality of insects. The Triazon insecticides provided maximum mortality then Polytrin C and Radiant which showed less effective against the PBW larvae (Rajput et al. 2017). Akhtar et al. (2018a, b) tested three insecticides (Triazophos, Cypermethrin and Bifenthrin) against *P. gossypiella*, however Triazophos provided better results as compared to other chemicals. During another experiment, it was observed that Diofenolan showed higher toxic effect on developmental stages of *P. gossypiella* (Tanani and Bakr 2018).

15.3.3.3 Biological Control

A large number of biological agents on *P. gossypiella* (Cheema et al. 1980) have been recorded, most of which are of no practical significance. Most of the natural enemies from the order Hymenoptera have been tested against *P. gossypiella*. Over 160 species from 43 genera of Hymenoptera have been found parasitic against the PBW. Genera like Apanteles, Brachymeria, Bracon, Elasmus and Chelonus are important to have natural enemies against PBW. Cheema et al. (1980) recorded 22 parasites of *P. gossypiella* during a survey from Pakistan and observed *Apanteles angaleti* only as significant.

15.4 Army Worm (*Spodoptera litura*)

The *Spodoptera litura* (Lepidoptera: Noctuidae) commonly called as Armyworm, is a destructive pest of cotton in all over the cotton producing countries. More than 120 host plants have been recorded for this pest. It also attacks on tobacco, castor, sunflower, chilies, groundnut, amaranthus and pulses (Xia-lin et al. 2011). It is found in China, Pakistan, Afghanistan, Indonesia, Korea, Japan, Srilanka, Taiwan, India, Burma and Thailand (Luo et al. 2000).

15.4.1 Biology and Life Cycle

Eggs are yellowish white in color laid in masses with 4–7 mm in size. Larvae are pale green to dark green in color, long and hairless body ranges up to 45 mm. Later instar larvae have three longitudinal lines, one on the top and one on each side; a line of dark specks keeps running on each side and two parallel lines of dark triangles keep running on top. Adults are 15–20 mm long with wingspan of 30–38 mm. The forewings are gray brown with white oblique bands and hind wings pale with brown margins.

15.5 Management

15.5.1 Chemical Control

Most of the insecticides are effective against this pest. Nagal et al. (2016) observed that Indoxacarb, Bifenthrin, Flubendiamide, Novaluron, Chlorantraniliprole, Emamectin benzoate and some biopesticides such as SlNPV, Btk and Azadirachtin were provided effective results against *Spodoptera litura*. Sood during the study in 2010 was observed that these pesticides gave effective results against this pest. The eco-friendly biopesticide Azadirachtin has been used as an antifeedant and pest growth regulator in IPM. It has shown strong biological activity against Armyworm. Azadirachtin inhibited the growth of *S. litura* larvae, which was resulted by structure destroy and size inhibition of the midgut (Shu et al. 2018).

15.5.2 Entomopathogenic Fungi

The entomopathogenic fungi (EPF) are effective bio-control option to suppress the population of this pest. Various strains of EPF were tested and provided effective results for this pest. Eggs and larval stages are most susceptible as compared to pupae against EPF. Asi et al. (2013) tested *M. anisopliae*, *I. fumosorosea* against eggs and larvae, and was found maximum mortality. Mortality was increased with increasing the conidial concentrations.

15.6 Cotton Thrips

15.6.1 Introduction

Thrips belong to family Thripidae in order Thysanoptera, are mostly found in tropical, subtropical and temperate areas of the world. These are phytophagous, mycetophagous, sporophagous or predatory insects. In cotton, a species (*Thrips tabaci*) of thrips is the serious pest (Shah et al. 2017). These considered as minor and as well as major pests of cotton in various cotton growing countries (Khan et al. 2013).

Thrips have wide host range. It attacked the vegetables and weeds which grown near the cotton fields. Its attack is severe in early stage when plants are rich in nutrients. Both adults and nymphs damage the cotton. These suck cell sap from leaves especially young ones, flowers, and fruits. The regular sucking of cell sap converts the green leaves into brown or silver in color and hardening of these (Natarajan 2007; Chisholm and Lewis 2009). The necrotic spots appear on bolls due to their feeding and opening and ripening of bolls may also be affected (Natarajan 2007) may result in 50% reduction of cotton lint in the United States. Overall production of cotton can also be reduced due to severe attack (Gahukar 2006). Thrips are reported as vector of viral plant diseases (Mandal et al. 2012; Larentzaki et al. 2008).

15.6.2 Thrips Biology

The life cycle of thrips consists of an egg, two larval stages and two to three pupal stages. The life cycle of thrips development depend upon the environment and food source. At low temperature, the life cycle exceeds and at high temperature life cycle become short.

Thrips oviposit in the plant tissues and eggs hatch in 6 days after oviposition. Single female lays 50–300 eggs at a time depending upon the species, host, environmental condition and quality of food source (Cook et al. 2011). The eggs are very small and kidney. Eggs from females without mating hatch into males while from mated females produce produce both males and females. The nymph is creamy to pale color. Nymph is apparently similar to adult but wingless. Thrips pupation period is about 6 days. The adult is elongated, stubble and yellow brown in color. Total life period from egg to adult is about 19 days. There are 15 generations of thrips in a year.

15.6.3 Host Range

Thrips species have single and multiple hosts. *Thrips tabaci* has wider host range than other thrips species. There are about 140 plant species in 40 families including crops and weeds which are hosts of thrips. The different hosts which are attacked by thrips are cotton, alfalfa, cucumber, asparagus, bean, beet, potato, blackberry, cabbage, carrot, cauliflower, celery, garlic, kale, leek, lettuce, onion, parsley, pea, pineapple, pumpkin, squash, strawberry, sweet potato, turnip, tomato and all small grains.

15.6.4 Distribution

Thrips tabaci has been reported to present throughout the world except Antarctica. It is mostly present in the temperate and the tropical regions and distributed in Asia (Suman and Usha 2015; Chang 1991), Africa (Razi 2017), North America, Central America and Caribbean (Rueda et al. 2007; Rueda and Shelton 2003), South America, Oceania and Europe (Ciglar et al. 2004).

15.6.5 Management

15.6.5.1 Seed Treatment

As early pest of cotton, seed treatment is necessary for its control. The farmers mostly use systematic insecticides like Thiamethoxam, Acephate and Imidacloprid for seed treatment to control thrips (Stewart et al. 2010). In California, insecticides are suggested by looking field situation. The insecticides are applied in the form of granules and liquid like Aldicarb. After 2–4 weeks planting, pesticides residual impact remains for controlling the pest. It has been observed that aldicarb gives control within 28–41 days after sowing. The imidacloprid gives control of thrips within 33 days after beginning of seed.

The foliar application can also be administered and varies according to condition and threshold like injury and immigration (Reed et al. 2010; Studebaker et al. 2010).

15.6.5.2 Cultural Management

Various cultural measures have been adopted to control the thrips which are summarized as; time of planting and harvesting, use of clean and healthy seed, selection of correct location for sowing, timely irrigation, mulching, pruning and thinning, removing alternate hosts, maintaining hygenic condition, use of resistant varieties, removal of infested plant material, crop rotation, sowing of attract crops and inter cropping. These all contribute to maintain thrips population in check.

15.6.5.3 Traps

15.6.5.3.1 Coloured Sticky Traps

Thrips are also controlled with the help of various colored traps. The sticky traps of various colours like blue, white, red, green and yellow used for attracting the thrips. Many studies have revealed that yellow color traps attract maximum thrips as compared to other colored. The blue and white is the second preference of thrips while least is red and green (Broughton and Harrison 2012; Prema et al. 2018). Some studies presented that the yellow, blue, neon green, silver and orange were less attractive than the neon yellow color traps. The blue sticky traps are also good preference for thrips.

15.6.6 Biological Control

Thrips are controlled by natural enemies consisting of predators, parasitoids, nematodes and fungi. The insect orders like Heteroptera (*Orius* spp., *Anthocoris* spp., *Dichyphus* spp., *Nabis* spp., *Geocorus* spp.), Thysanoptera (predatory thrips like *Neoseiulus* spp.), Neuroptera (*Chrysoperla* spp.), Coleoptrra (*Coccinella* spp., *Dalotia* spp.), Diptera (*Syrphus* spp.) (Greenberg et al. 2009) and spiders have been proved effective predators of thrips. Some fungi and nematodes like *Beauveria bassiana, Metarhizium anisopliae* and *Steinmema* spp. are used as biological control. Many hymenopterous parasitoids are used for controlling larvae and eggs of thrips. All these parasitoids belong to superfamily Chalcidoidea.

The Trichogrammatidae includes egg parasitoides. The larval parasitoids are included in genera like *Pastichus* and *Pediobius*, *Ranisus*, *Goetheana*, *Thripobius* and *Entedonastichus* (Eulophidae). All of these are solitary and internal parasitoids of larvae as well as pupae. *Thripobius semiluteus* was introduced from Australia to use for control of thrips in California. *Goetheana shakespearei* and *Selenothrips rubrocinctus* had also been used to control the thrips. The predors parasitoids and entomopathogen like fungi, virus, bacteria and nematodes decrease the various species of thrips population (Hulshof et al. 2003). Among pupal predators entomopathogenic nematode, Hypoaspis mites, rove beetles are important.

15.6.7 Botanical Control

The chemicals which are extracted from plants are known as botanical extracts. These extracts from plants like neem, castor bean and garlic are use in mixtures with insecticides for pest management. Neem is good and susceptible to insect resistance while garlic is less stable into environment. These are ecofriendly, biodegradable and harmless for human, non-target life and ecosystems. These can reduce the thrips population and increase mortality. Due to neem extracts, thrips feeding reduces, behavior changes (Schmutterer 1990), oviposition delays, fecundity and fertility reduces. The pyrethrins present inside the Chrysanthemum extract are neurotoxic and give fast control. Extracts from plants like *Datura stramonium*, *Calotropis procera*, *Nerium indicum* (Din et al. 2016), *Azadirachta indica* and *Dodonae angustifolia* have been used succesfully against thrips (Jensen et al. 2001).

15.6.8 Chemical Control

The spinetoram, gamma-cyhalothrin plus chlorpyrifos, and the pyrethroids bifenthren, lambda-cyhalothrin, gamma-cyhalothrin, and beta-cyfluthrin have been suggested in Virginia for thrips control (Herbert 2010). A study carried out in University College of Agriculture, Bahauddin Zakariya University, Multan using to check the efficacy of Advantage, Confidor, Talstar, Mospilan, Tamaron, Polo and Actara against thrips. The results exhibited that Polo, Advantage and Confidor are effective in descendent order mentioned here, and Talstar was least effective.

Another study from Pakistan narrated Polo and Confidor as extremely effective while Cascade as the least. In a study fromt India showed that Thiomethoxam, Fipronil, Acetamiprid and Imidachloprid provided 80%, 76.55%, 68% and 72% control respectively, and Triazophos was least effective (55.20%) (Sreekanth and Reddy 2011). It had also been observed that Profenofos 50 EC, Flonicamid 50 WG, and Imidacloprid suppress 45% population of thrips while 83.06% population was controled due to Fipronil 5 SC (Boda 2014).

15.7 Whitefly

15.7.1 Introduction

The whitefly, *Bemisia tabaci* (Gennadius) is a polyphagous pest around the globe. It is vector of more than 100 plants diseases and damages more than 900 species of plants (Simmons and Abd-Rabou 2008). The *B. tabaci* is now considered as species complex of various biotypes. It can cause severe damage to cotton crop by sap sucking and excreting honey dew consequently allows sooty mould to grow on leaves in reduction of photosynthetic activity. By direct feeding, yield can be reduced, while lint quality deteriorates due to indirect damage caused by honeydew and through transmission of cotton leaf curl virus (CLCV) disease.

15.8 Biology and Life Cycle

The yellowish white stalked eggs are laid singly under leaf surface (Bethke et al. 1991) which are converted into yellowish, sub-elliptical scale like nymphs which are found in large numbers on underside of leaves. Nymphs change into pupa like stage called pseudopupa and resemble like nymphs having brownish opercula.

The adults are whitish with yellowish body dusted lightly with waxy white powder. Female with size of 1.1–1.2 mm is larger than male and has longer antennae. Total life cycle of *B. tabaci* comprises of 14–20 days depending on weather.

15.9 Management

15.9.1 Exclusion

In green houses, whiteflies can be checked by sealing openings with screening material. Due to its small size, screens with mesh size of 0.27 × 0.82 mm are better to avoid their entrye.

15.9.2 Detection / Scouting

The pest scouting is essential on regular basis to avoid economic damage by all insect pests and also true for *B. tabaci*. The crop inspection on weekly intervals by trapping adults with sticky cards or observing leaves for presence of nymphs and adults can be a better strategy for monitoring whitefly populations (Shun-xiang et al. 2001).

15.9.3 Cultural Control

Growing trap crops for redirecting whitefly population can be an effective strategy for management of this pest in cotton. Such tactic may help to break population flare-up in nurseries and green houses (Shun-xiang et al. 2001).

15.9.4 Biological Control

Some bio-control agents used for managing *B. tabaci* include predators (*Amblyseius swirskii*, *Delphastus catalinae*), parasitoids (*Eretmocerus eremicus, Encarsia* spp.) and entomopathogenic fungi (*Beauveria bassiana, Isaria fumosorosea*) (Shun-xiang et al. 2001).

15.9.5 Chemical Control

Many chemical pesticides are being implied to control this notorious sucking pest of cotton. In Pakistan, a study showed that Pyriproxyfen and Spirotetramate was proved more effective while Imidacloprid and Acetamiprid was less against whitefly population (Iqbal et al. 2018). Contradicting to that, Babar et al. (2013a, b) reported Imidacloprid and Acetamiprid as showing highest mortality of whitefly. Another field study was carried out to determine the effect of some insecticides (Cyhalothrin, Profenofos and Imidacloprid) against whitefly population. The study was revealed that Profenofos was the most effective followed by Cyhalothrin against whitefly population while Imidacloprid proved less toxic (El-Sherbeni et al. 2019).

Due to excessive use of insecticides against insect pests, whitefly has become resistant against various group of insecticides such as organophosphates, pyrethroids, and neonicotinoids (Naveen et al. 2017). It has also developed restance against various insecticides such as Chlorfenapyr, Emamectin benzoate, Avermectins and Abamectin (Ahmad and Akhtar 2018).

15.10 Cotton Jassid

15.10.1 Introduction

Jassid belongs to order Homoptera, family Cicadelidae and the subfamily Typhlobinae. The cotton jassid ia also known as cotton leafhopper, green jassid, okra leafhopper, eggplant leafhopper and Indian cotton leafhopper (Akmal et al. 2018).

Many species of genus *Amrasca* found worldwide are reported to damage the cotton and *Amrasca biguttula* is important.

15.10.2 Host Range

Jassids are polyphagous pests (Sreejith et al. 2015) and cause economic losses in many crops like cotton, potato, maize, sorghum, brinjal, cowpea, okra, sunflower, beetroot, mulberry, pigeon pea and China rose (Khatri et al. 2013; Akbar et al. 2012; Chandani and Sathe 2015).

15.10.3 Life History

Banana like eggs are whitish in colour. The length and width of eggs are 0.5 mm and 0.1 mm, respectively. Jassid lays eggs by inserting these in plant tissues and female lays maximum 15–29 eggs. Nymphs are pale yellowish in color which remain in lower side of leaves at daytime. There are five nymphal instars. These are similar to adult but varies in size and wingless. Adults are pale green, wedge shape and 3.5 mm in length. The forewings are shiny and carries black spots, while hind wings are membranous.

The life period of both male and female consists of 22 and 26 days, respectively.

15.10.4 Damage

Both nymphs and adults suck cell sap, weak the plant health by injecting toxins, convert the leaves color into yellowish and damage fruits and buds. During sucking cell sap, fruits drop and sooty mould grows on leaves which affects the photosynthesis ultimately reduces the yield (Sathe et al. 2014). The severe attack can reduce the number of bolls on plants.

First 2 instars nymphs suck the cell sap from leaves veins and remaining from all parts of the plants. The leaves become cup shape and turn downword and yellowish hence growth of young plant stops (Pontarotti 2010) and cause "hopper burn" due to severe attack.

15.10.5 Distribution

This notorious pest is distributed throughout the cotton growing areas of the world including South and Southeast Asia (Babar et al. 2013).

15.11 Management

15.11.1 Seed Treatment

In cotton, Carbosulfan and Imidacloprid are used for cotton seed treatment. These insecticides are mixed with seeds and give best control against various pests like jassid. The seed treated with Imidacloprid 70 WS @10 gm / kg and Carbosulfan 25% DS @ 30 g / kg of seed give highest germination and good pest control (Sajjanar 2018).

15.11.2 Traps

Sticky traps with various colours such as blue, green, yellow, white and black are used for monitoring and controlling various pests like jassid which prefer yellow and orange. Chu et al. (2000) suggested that yellow and green traps were more attractful for jassid as compared to red, white, black and blue ones. Studies also showed that jassid were less striking to red color traps than yellow with red border (Raja and Arivudainambi 2004).

15.11.3 Biological Control

Arthropod predators such as ladybird beetles, spiders and Chrysopa help to suppress jassid population in fields (Simmons and Shaaban 2011). Larvaeof *Chrysoperla carnea* Stephens, are most common predator of various small and soft bodied (Michaud 2001) insect pests like jassid. Lady bird beetle species *viz., Coccinella septempunctata* (Deligeorgidis et al. 2005) and *Coccinella undecimpunctata* (Pascua and Pascua 2002) are efficient predator of jassid.

Some coccinelid beetles like *Micraspis crocea*, *Menochilus sexmaculatus*, *Cyrtorhinus lividipennis* and nabid bugs are used as biological control agents for jassid (Pascua and Pascua 2002). The spiders belonging the families Tetragnathidae, Thomisidae and Argiopidae are also pedators of jassid and feed on nymphs and adults.

15.11.4 Cultural Control

Cotton sown between 15 April to 31 May may help in less jassid attack. Plant spacing also affects the pest population. Microclimate of the cotton field affects jassid population as high pest population is observed in denser crop and vice versa.

Excessive use of nitrogenous fertilizers promotes jassid population because it gives lush green look to crops that attracts jassid (Nagrare et al. 2018). Removal of alternative hosts like okra, sowing of trap crops like cow pea and moong bean, removal of weeds and rational use of irrigation and nutriets may help in jassid management (Eyhorn et al. 2005).

15.11.5 Botanical Control

The various medicinal plants like neem (*Azadirachta indica*, *A. juss*), *Eucalyptus* spp., tobacco and other have toxic qualities and are used as pesticides for controlling the pests including jassids. These are biodegradable, ecofriendly and don't harm the beneficial fauna.

15.11.6 Chemical Control

Chemical control is the part of integrated pest management (IPM), which quickly suppress the pest population in very short period of time (Gogi, et al. 2006; Kranthi et al. 2002). Various insecticides are used by several searchers to check the efficacy of insecticides in laboratories and fields conditions against the different crop pests including jassid (Khattak et al. 2006; Pradeepa and Regupathy 2002).

The various products of insecticides are used to control pests worldwide throughout the year (Ashfaq et al. 2010). The insecticides which use by various authors for the management of pests in cotton field were neonecotinoids (Khan et al. 2011) and pyrethroids and organophosphate insecticides. The several chemicals are being used to control jassid in cotton throughout the world. Both Confidor, Mospilan and Baythroid give better control of jassid in cotton. Studies prove that Crown, Actara, Asualt (Abbas et al. 2012), Rani, Acetamiprid (Khan 2011), Novastar, Deltaphos and Confidor (Awan and Saleem 2012) are effective against jassid. Afzal et al. (2014) reported that Imidacloprid, Diafenthiuron and Acetamiprid gave highly effective control against jassid. Confidor, Polo and Actara gave better control against it after 1, 3 and 7 days after treatment (Akbar et al. 2012).

15.12 Red Cotton Bug

Red cotton bug (*Dysdercus* spp.) is hemipteran the family of which is Pyrrhocoridae and considers as a major pest of cotton growing areas, due to lint discoloration (Ashfaq et al. 2011), fast reproduction (and ineffective control (Jaleel et al. 2013).

15.12.1 Host Range

It is polyphagous sucking pest with main alternative hosts are hollyhock, okra and other plants belonging to families Bombacaceae and Malvaceae (Sarangi et al. 2012). The main host of red cotton bug is cotton. Another study carried narrated cotton, okra and simal as its favorable host (Naqqash et al. 2014).

The study revealed that cotton is the preferable host of red cotton bug due to vigorous oil content, number of eggs were highest on cotton than okra and simal. The cotton and simal have maximum oil contents but toxic chemicals in simal (Heikal et al. 2012) affect the preference of pest and pest show negative response.

15.12.2 Biology

Both nymphs and adults of red cotton bug feed on the bolls and seeds of cotton. It has piercing sucking mouthparts with the help of which it sucks cell sap and feed on and inside of the bolls.

Female lays about 70–80 eggs in moist soil, under plant debris and cracks or crevices. Eggs are creamy yellow, smooth and oval shape which before hatching change into yellowish orange the incubation period of these is 6.18 days. About five nymph instars present in red cotton bug. First, second and third instar are orange and red in color while fourth is creamy with dark shape wing pads. The nymph takes 50–60 days to become an adult. Adults have wings with black pads present on forewings. The hind wings are membranous and covered by forewings. The females are larger than the males in size. The antennae and legs are also black. There are several generations of red cotton bug in a year. It completes their life cycle in 51–60 days.

15.12.3 Damage

Both adults and nymphs suck the sap and insert fungal spores in the bolls. This pest attacks on the newly developed fruits, makes pores into the fruits due to which new plasmid outgrowth starts and through the pores, microorganisms enter the fruits. During this mechanism, a fungal disease "stigmatomycosis" which cause by filamentous fungi, *Ashbya gossypii* develop). Some other species of cotton staining fungi include *Nematospora gossypii* (Jaleel et al. 2013) and *Eremothecium gossypii*. During feeding on cotton bolls, all fungi mentioned above stain the lint. The main damage of red cotton bug is lint staining due to which quality of lint reduces (Khan and Qamar 2012; Jaleel et al. 2014). Due to staining, the pest is also named as cotton stainer. In the case of severe attack of red cotton bug, the bolls open badly.

15.12.4 Distribution

Red cotton bug is distributed in all cotton growing countries of the world like India, Pakistan, Japan, Srilanka, Australia, Solomon island and Burma. Some species also reported in Australia and Southeast Asia.

15.13 Management

15.13.1 Cultural Practices

The cultural practices which are adopted for red cotton bug include plant population, sowing dates, fertilizer, irrigation and weed management. The red cotton bug can reduce by the removal of cotton sticks and alternate hosts mostly from Malvaceae family. The time of sowing is very important factor which controlled the various pests of crop and helpful in getting the profitable yield (Showler et al. 2005).

15.13.2 Biological Control

The fungus genera like *Beauveria*, *Isaria*, *Metarhizium* and *Lecanicillium* have been identified and developed for managing pests like red cotton bug. These extensively used in various countries like the United States. About 92.30% population of red cotton bug has been reported to reduce due to fungus, *Metarhizium anisopliae* (Sahayaraj and Borgio 2010).

Some predatory mites are also reported as natural enemies of red cotton bug which include *Hemipteroseius indicus*, *Hemipteroseius indicus* (Sarangi et al. 2012) and *H. vikramias*. The later was reported from India. These mites are site specific and feed on whole body of host. These suck the hemolymph of red cotton bug and after weakening, cause death in them. A predator of red cotton bug known as *Antilochus coqueberti* (Hemiptera) has been reared in Central Cotton Research Institute (CCRI), Multan and is proved as effective biocontrol agent (Noman et al. 2016).

15.13.3 Chemical Control

Chemical control is significant and rapid control strategy in management of pests globally. A chitin synthesis inhibitor like flucycloxuron was used by Khan and Qamar 2011 for the management of many polyphagous pests especially *D. koenigii* at nymphal level. The study revealed that after 72 h of application, 76% fourth instar died at 50 μg/ml dose of Lufenuron. Chlorfenpyr showed 80% mortality after 72 h of treatment.

The insect growth and development has also been affected by a chitin synthesis inhibitor, Lufenuron that reduces the feeding of insect at high dose (Gelbic et al. 2011). The lipophilic properties of Lufenuron interact with the cuticle of insect.

The different insecticides like Imidacloprid, Deltamethrin, Lambda cyhalothrin, Gamma cyhalothrin and Cyfluthrin were used to determine their efficacy on hemocytes of red cotton bug (Sarwar et al. 2018). Chlorpyrifos has also proved effective against red cotton bug. These insecticides change the haemocytes cell and immune response. It has been observed that deltamethrin increase the plasmatocytes (Teleb 2011; Fatima et al. 2016). Another study recorded that Deltamethrin, Lambda cyhalothrin and Cypermethrin reduce pest population 93.8%, 70% and 78.7%, respectively. Thus, results have been detected that Pyrethroid showed 100% mortality while malathion, dimethoate, chlorfenapyr suppress 33% pest population.

15.14 Dusky Cotton Bug

15.14.1 Introduction

Dusky cotton bug (*Oxycarenus* spp.) has attained now a day, the status of major pest in cotton growing areas like Pakistan. It is usually called as cotton stainer or seed cotton bug. It is sucking pest of cotton. It stained the lint during ginning through which quality of cotton is reduced and fetches low market value. Sewify and Semeada (1993) reported 32%, 6.8% and 6% reduction in seed weight, yield loss and seed oil, respectively due to its infestation. Widely sowing of Bt cotton varieties and minimum use of insecticides against chewing pests are main reasons of becoming dusky cotton bug a major pest (Ullah et al. 2016).

Due to its severe attack, quality and quantity losses occurred in cotton. The nymph and adult of dusky cotton bug (DCB) suck the cell sap from plant leaves and oil contents from seeds (Akram et al. 2013) resulting in embryo injury, reduction in seed viability so seed remains light in weight, oil and yield. About 6% losses in seed contents occur due to attack of DCB. An unpleasant smell produces due to its severe infestation on cotton.

Dusky cotton bug first appears in July then its population increases from August to September. In these months the population of dusky cotton bug increases behind the threshold level. The maximum population of dusky cotton bug is observed in September to November (Shah 2016). Although weather influences its population but the up and down in temperature have no considerable effect while humidity affect pest population.

15.14.2 Host Range

The alternative hosts of DCB are avocado, corn apple, figs, dates, guava, grapes, peach, pineapple, pomegranate, mango, moringa, lemon, cotton, okra and chillies (Shah 2016). The neem is also a favorable host of dusky cotton bug (Abbas et al. 2015). The weeds, dried leaves and grasses are the overwinter places for the insect and during this period insect avoids mating. These also overwinter in ginning factories and houses under un-ginned cotton.

15.14.3 Biology

15.14.3.1 Adult

Adult is 4–3 mm long in size with white wings and black thorax. About 110 eggs laid by female on host plant seeds in batches or singly. The new leaves or bolls are also preferred for egg lying. The eggs of DCB are cigar shaped and yellowish. The colour of eggs changes into light pinkish after third day of laying (Srinivas and Patil 2010). The length of egg is 1.06 mm. After hatching, it goes through five nympal instars. The nymphs are pink in color and orange abdomen with legs and antennae are also pink. During warmer days or weather, the colour of nymph changes. They have no ocelli and are wingless. The first three nymphals instars are similar in shape. Under the controlled condition, the life period of DCB is 33–51 days and there are 6–7 generations in a year (Abbas et al. 2015).

15.14.4 Geographical Distribution

It is distributed throughout the world including in Pakistan, India, Africa, South America and Caribbean Basin (Jaleel et al. 2014). It has also been reported from Egypt, Sudan, Kenya, Malawi, Angola, Uganda, Congo, Tanzania, and many other African countries (Schmutterer 1969).

15.15 Management

15.15.1 Cultural Practices

The cultural practices which adopted for dusky cotton bug management are: removal of alternate hosts like okra and collecting both nymph and adults through betting the bolls or fruits.

15.15.2 Chemical Control

Several types of strategies are being used for insect pests control of cotton. One of them is chemical control by using synthetic insecticides which shows quickresults adopted by general farmers. Various groups of insecticides like organophosphate, pyrethroid, and novel chemistry are used for the management of various insect pests including dusky cotton bug (Ullah et al. 2016).

It has been reported that Triazophos showed 85% control while Imidacloprid 79.2% and Profenofos 78.0%. It has been observed that Dimethoate and Spinosad gave 75.0% and 12.5% mortality, respectively while Deltamethrin 2.5 EC has proven effective (Akram et al. 2013). This study resulted that Triazophos has proven effective while Spinosad shown lowest control. It has been shown that Goldstar, Karate and Delegate are proved effective against dusky cotton bug.

15.15.3 Botanical Control

Many plant extracts have been reported as botanicals against dusky bug. A study carried out in Faisalabad, resulted that *Nicotiana tabacum* and *Calotropis procera* were effective against DCB as they gave 76% and 74% mortalities, respectively. After 24 h of treatment, *Azadirachta indica, Moringa oleifera* and *Citrus sinensis* caused mortalities about 58.33%, 43.3% and 35.7%, respectively (Abbas et al. 2015). Another study reported that *N. tabacum* recorded maximum mortality (96.91%) while *Ocimum sanctum* showed minimum (52.91%) of dusky bug at 5% concentration (Saleem et al. 2018).

15.15.4 Biological Control

Many predators, parasites and fungus species are reported as biocontrol agents for DCB management. Some entomopathogenic fungi such *as B. bassiana, I. fumosorosea and M. anisopliae* are used for its management. The population of dusky cotton bug suppressed through these agents. These organisms tested against the dusky cotton bug resulted that *B. bassiana* most effective than *I. fumosorosea* and *M. anisopliae* (Khan et al. 2014).

15.16 Resistance

Resistance is defined as a genetic change in an organism in response to selection by toxicants. The development of resistance does not automatically lead to impairment of pest control. For instance, low levels of resistance may be observed in the laboratory without immediate problems arising in the field. Resistance is a threat in the management of cotton pests thus a very effective strategy and planning should be needed to overcome this problem. With the judicious use of species specific pesticides, by adopting alternate control measures and by producing tolerant crop varieties, the resistance in insects against pesticvides can be managed.

It is being estimated that an overall 10% of the world produced pesticides is being utilized on the cotton only around the globe. Among the total pests of cotton, 550 have developed resistance to one or more insecticide. It has been noted that in the globe, 34 insect pests had developed resistance to three insecticide classes and among 34 resistant insects, 19 occurs in the USA alone (Roush and Daly 1990).

Below in the table, a list is being provided to show insect pest species of cotton which have been reported to be resistant against commonly available insecticides.

15.16.1 Insecticide Resistance in Sucking Pests

Sr. no.	Insects	Pesticides	Resistance (Folds)	References
1	*Aphis gossypii*	Organophosphates	Yes	Kung et al. (1961)
		Primicarb	1350	Delorme et al. (1997)
2	*Empoasca devastans*	Endosulfan, Monocrotophos, Cypermethrin, Phosphamidon, Dimethoate, methyl demeton and Acephate	Yes	Jeyapradeepa (2000)
	Amrasca devastans	Organophosphate insecticides, Metasystox, Diamethoate and Phosphamidon	Yes	Praveen (2003)
3	*Bemisia tabaci*	Dimethoate and Monocrotophos	High	Dittrich and Ernest (1983)
		Buprofezin and Imidacloprid	Yes	Cahill et al. (1996)
		BHC, Endosulfan, Diamethoate, Phosalone, Acephate, Monocrotophos, quinalphos and Carbaryl	Yes	Prasad et al. (1993)
		Methomyl and Monocrotophos	High	Kranthi et al. (2002)
		Cypermethrin	Moderate	Kranthi et al. (2002)

15.16.2 Insecticide Resistance in Lepidopteran Pests

Sr. no.	Insects	Pesticides	Resistance (Folds)	References
1	*Heliothis armigera*	Monocrotophos	65	Kranthi et al. (2001)
2		Chlorpyrifos	82	Kranthi et al. (2001)
3		Quinalphos	15	Kranthi et al. (2001)
4		Methomyl	22	Kranthi et al. (2001)
5		Monocrotophos	High	Wu et al. (1997)
6		Methomyl	>300	Ren et al. (2002)
7		Methomyl	>200	Ren et al. (2002)
8		Monocrotophos	720	Ahmad et al. (1995)
9		Endosulfan	4 to 37	Kranthi et al. (2001)
10		Cypermethrin	High	McCaffery et al. (1988)
11		Pyrethroids	25 to 205	Ahmad et al. (1997)
12		Cypermethrin	17	Ernst and Dittrich (1992)
13		Fenvalerate	1361	Cheng and Lieu 1996
14		Deltamethrin	911	Cheng and Lieu (1996)
15		Fenvalerate	6	Gunning (1993)
16	*Pectinophora gossypiella*	Azinphosmethyl and Permethrin	Yes	Osman et al. (1991)
17	*Earias vittella*	Monocrotophos	70	Sarwar (2016); Kranthi et al. (2002)
18	*Spodoptera litura*	Endosulfan, Carbaryl and malathion	Yes	Verma et al. (1971)
19		Quinalphos	13	Armes et al. (1996)
20		Monocrotophos	362	Armes et al. (1996)
21		Methomyl	19	Armes et al. (1996)

15.17 Conclusion

Climate change is global phenomena whcich has encompassed whole globe and affecting ecosystems badly ultimately threatening lives of humans, animals and plants seriously. The effects of this phenomina triggered manifold with amalgamation of anthropogenic activites that not only exerting adverse pressures on life on this planet but also modifies behavious, culture, food availability, natural habitat destruction that result in onset of new diseases and pests of crops, animals and human all around the world.

Therefore, crops in many areas are facing new insect pests and diseases resulting in a threat of food scarcity for a human population of more that seven billion which is increasing day by day. Although much results caused by this is beyond human control, but its severity can be minimized by evolving new varieties, by developing new regimes of pest control and by adopting ecofriendly approaches for raising crops so that harm to ecosystems can be minimum. For this, purpose, scientists involving in above mentioned tasks will have to work on war footing to save life for present and also for the future.

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Chapter 16
Plant-Microbes Interactions and Functions in Changing Climate

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Abstract Climate change is one of the hot topics of the current century because it is not only an issue to our health but also to agriculture, forestry, biodiversity, ecosystem and supply of energy. Climate change is occurring mainly due the emission of greenhouse gases like nitrous oxide (N_2O), methane (CH_4) and *carbon dioxide* (CO_2) and the drastic changes due to these gases are predicted to change the level and various parameters of life in the changing environment. The increase or decrease in the function and composition of terrestrial microbial community is both directly and indirectly affected by climate change. The increasing temperature successively

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_16

causes to increase the structure of microbial community and meanwhile accelerate several processes like methanogenesis, respiration, decomposition and mineralization. When climate change made some changes in the prevailing environmental conditions it will arise changes in plant physiology, root exudation, alteration in signals, C/N ratio, abundance, composition and diversities of soil microbial communities. As a result the environmental changes brought about by climate change also affect the performance of beneficial microbes on plant growth, health and root colonization.

In the current book chapter, we have discussed the impacts of climate change parameters like CO_2, drought, precipitation and temperature on plant microbes interaction. Furthermore, this review also indicate that how microbes in the plant rhizosphere respond to the prevailing climatic conditions in the terrestrial environment.

Keywords Plant-microbes · Climate change · Microbial response · Carbon dioxide · Environmental changes

16.1 Introduction

The crucial concerns of the current century are climate change, sustainable environment, supply of energy and good health. These are considered as the main challenges of the day and especially climate change is one of the hot topics (Abatenh et al. 2018). Since, the predicted patterns of climate change are becoming main challenges in the area of agriculture, forestry, biodiversity and ecosystem (Lepetz et al. 2009). Climate change is occurring mainly due the emission of greenhouse gases like N_2O, CH_4 and CO_2 (IPCC 2007). The drastic changes due to these gases are predicted to change the level and various parameters of life in the changing environment (Houghton et al. 2001). Moreover, the effect of predicted climate change is expected from individual species population to eco-region level (Lepetz et al. 2009). It has also been documented that the levels of atmospheric CO_2 generated naturally or anthropogenically may increase temperature of the global surface between 1.8 and 3.61 °C by the year 2100 (IPCC Climate Change 2017; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). This increase in temperature is predicted to decrease soil water (Le Hou'erou 1996) in some areas and may induce drought in various areas of the world that will ultimately affect the plant-microbe interaction (Compant et al. 2010) as well as their communities and function in the soil (De vries and Griffiths 2018).

The above and below ground terrestrial ecosystem is affected by climate change, both directly and indirectly. The effects of global change like increasing CO_2, changes in precipitation, temperature and nitrogen will affect the population of plant species above the ground (Tylianakis et al. 2008). While, belowground, the climate change will affect the amount of carbon and architecture of the root zone that will indirectly affect the microbial biomass, composition and community of microbes. Moreover, climate change induced by high level of atmospheric CO_2 will result in increasing intensity of extreme weather events, elevated temperature and change in rainfall patterns (IPCC 2014). All the mentioned climate changes will pose direct and indirect impact on the plant physiological processes as well as soil microbes community and composition (Bardgett et al. 2013).

In the current chapter we are discussing both the direct and indirect impacts of climate change on soil microbes interactions and the consequences which arise and affect their function and community in the wider ecosystem. Climate change effects on plant soil microbe and microbe microbe interaction will definitely intervene in important process like mineralization, plant chemistry, community and other ecological functions (Gilman et al. 2010; Steinauer et al. 2015). The soil microorganisms are the important component of carbon and nitrogen cycles and contribute well in the emission of greenhouse gases like CH_4 and CO_2 which again take part in climate change (Microbiology Online 2015). During organic matter decomposition, the heterotrophs emit greenhouse gases while the Photosynthetic microorganisms consume the CO_2 from the atmosphere and thus this balance between the two processes determine the net carbon flux across ecosystem and mainly depend on temperature. These processes highlight that soil carbon flux is mainly due to microbial responses (Weiman 2015) which not only immobilize but also release a large amount of carbon to the atmosphere (Zimmer 2010) and hence it can also be confirmed that the greenhouse gases including N_2O, CO_2 and CH_4 are released to the atmosphere due to soil microbes (Singh et al. 2010).

When climate change made some changes in the prevailing environmental conditions it will arise changes in plant physiology and root exudation. The increasing CO_2 often increase the carbon allocation of root zone and hence affect the composition of root exudates. Further impacts documented due to climate change include alteration in signal compounds, C/N ratio, nutrients and chemo attractants availability (Kandeler et al. 2006; Haase et al. 2007). Likewise, high temperature and drought affect the activities, abundance, composition and diversities (Drigo et al. 2008) of soil microbial communities. As a result the environmental changes brought about by climate change also affect the performance of beneficial microbes on plant growth, health and root colonization.

The increase or decrease in the function and composition of terrestrial microbial community is both directly and indirectly affected by climate change. The increasing temperature successively causes to increase the structure of microbial community and meanwhile accelerate several processes like methanogenesis and respiration. The climate change can accelerate the different phenomenon like heat waves, extreme heat, flood rises, poor air, natural disaster, intense storms and heat waves that will ultimately cause injury, illness and death to both biotic and abiotic components. Due to climate change different microbes like fungus, bacteria, algae and archae will trigger global warming through organic matter decomposition and amount of CO_2 released in the atmosphere (Swati et al. 2014; Weiman 2015).

Both the microbial biomass and their enzymes in the soil environment can efficiently take part in stimulating of warming and it is because during decomposition organic matter release carbon based toxic materials to the wider environment but at the same time it has also been observed that it can prevent climate change. Similarly, temperature can affect microbial physiological property and their enzymes activity directly and therefore the microbes using carbon can efficiently determine the response of carbon to climate change (Bardgett et al. 2008; Allison et al. 2010).

It is essential for the toughness of microbial communities that there should be some dispersal mechanisms and connectivity amongst them and it is because when the regional dispersal become successful it affects the maintenance of local and confined diversity (Matthiessen et al. 2010; Lindstrom and Langenheder 2012). It has also been shown that proper connectivity and the group population is important for the proper function and survival of microbial communities (Altermatt et al. 2011; Carrara et al. 2012; Wahid et al. 2019; 2016a, b) but for soil such information is not yet proved well. Due to heterogenous nature (Ritz et al. 2004) the dispersal mechanism can play a crucial role in the recovery of soil microbial communities and also the spatially dispersed soil microbial population can be hinder because of low moisture content (Treves et al. 2003).

On the other hand, some microbes in the soil can also disperse through above ground mechanisms. For example fungi that depend on active dispersal mechanisms (Roper et al. 2010) can show more resistance than bacteria lacking active dispersal mechanisms (Kasel et al. 2008). Furthermore, due to large population bacteria and small body position, phytoplankton cells and archaea are suggested to disperse passively (Finlay and Clarke 1999).

The microbes like fungi and bacteria has been found to play important role in ecosystem functions like cycling of mineral nutrients (Baseer et al. 2019), decomposition of biological materials as well as pathogen of animals and plants. Recently, scientists are paying much attention to the direct effect of climate change on microorganisms and especially their direct contact with sunlight if they are present in litter or foliage surfaces. The effects of climate change on the microbes biodiversity and species composition change have been well documented and most of these changes have been found to be related to the tolerance of different species and strains of fungi and bacteria (Johnson et al. 2002; Djanaguiraman et al. 2010; Fritioff et al. 2005). The arbuscular mycorrhizal fungi form symbiosis with other plants and help in absorption of nutrients is thought to be indirectly affected by UV-B by the time its host plants shoot is exposed (Braga et al. 2001). With regards to climate change both beneficial microbes and plant pathogens have gained more attention than animals pathogens because some bacteria and fungi can be pathogenic for plants and animals (Zaller et al. 2002; Jacobs and Sundin 2001). Several environmental factors can reduce or increase the plant growth and productivity as well as disease incidence. When the severity of disease is high then it is thought to be involved in plant tissue modifications on the other hand when the severity is decreased then it may cause the direct damage to host plant or create some changes in the host plant (Van de Staaij et al. 2001). The aim of the current review is to discuss the impacts of climate change parameters like CO_2, drought, precipitation and temperature on plant microbes interaction. Furthermore, this review also indicate that how microbes in the plant rhizosphere respond to the prevailing climatic conditions in the terrestrial environment.

16.2 Impacts of Elevated CO_2

Elevated CO_2 has stimulatory impacts on various physiological parameters of the plant including the growth, reproduction, photosynthesis and yield (Ainsworth and Rogers 2007). Though, the rising level of CO_2 will also enhance the incidence of extreme weather events like drought and heatwaves, which are harmful to crop expansion and yield (Wang et al. 2013; Gray and Brady 2016). Similarly, rising CO_2 concentrations will also stimulus the consequence of plant-pathogen interactions (Eastburn et al. 2011) with rhizosphere inhabiting microorganisms (Gschwendtner et al. 2016) thus disturbing plant growth, development and plant yield. In additions, rising atmospheric CO_2 can enhance photosynthetic activity and plant production (Ainsworth and Long 2007). The elevated rise in carbon dioxide can stimulate various processes in plants including photosynthesis, respiration and plant production (Ainsworth and Long 2007; Khan et al. 2019). The enhanced carbon sequestration and its assimilation in the plants may balance the enhanced CO_2 emissions. Improve carbon sequestration under enhanced levels of CO_2, can only occur if (i) carbon input in the soil are sustainable (ii) the rate of carbon loss will be less over to carbon inputs.

While it is uncertain that how the higher CO_2 will effect the soil carbon additions and degradation in long terms. Specifically, the relationship between soil carbon inputs and breakdown is not quite linear, subsequently, the processes are inter-reliant; for example, soil carbon inputs impact degradation and degradation impacts soil nutrient uptake, which is the feedback response of the plant growth to the rising level of CO_2. So far, various studies has contrasting outcomes with respect to the effects of rising CO_2 on nutrient turnover and plant growth, including both positive and negative feedbacks in the carbon and nitrogen (N) turnovers.

Enhanced soil carbon inputs increased the nitrogen mineralization in some researches, however, hindered it in others. Such as the results of one study revealed that enhanced C additions under rising CO_2 enhanced the population of soil microbes, thus total rates of nitrogen mineralization (Freeman et al. 2009). In addition, Diaz et al. (1993) also revealed that enhanced C inputs in the rising level of CO_2 enhanced the antagonism among the soil microbial growth and plants for soil nitrogen, leading to a reduction in nitrogen uptake. Similarly, nitrogen fertilization may counter balance the reduction in nitrogen availability in the rising level of CO_2 (Norby 2007).

Therefore, it remains unclear how initial increases in soil C input under elevated CO_2 feedback to microbial regulation of N availability. In addition, it is uncertain how the increase or decline in N availability ultimately feeds back to soil C sequestration. If sufficient N is available, enhanced plant growth and soil C input under elevated CO_2 are likely to be sustained, resulting in net soil C sequestration (Luo et al. 2004). However, it has also been contended that abundant soil N uptake might consecutively increase the soil C breakdown (Norby 2007). Therefore, the enhanced CO_2 emission rates might offset a probable rise in soil C assimilation. The uncertainty adjacent to the link of soil C addition to soil microbial N-transformations, and the role of N uptake for the potential of soil C-sequestration, makes it challenging to envisage whether the soil can act as a C sink to mitigate rising atmospheric CO_2.

Impact of elevated CO_2 can accurately be predicted in the long-term field studies and have a key role in the soil carbon turnover, nitrogen cycling, and plant production. For example, Free Air Carbon dioxide Enrichment (FACE) trials are the most suitable field experiments for such research endeavors. The application of FACE approached has permitted for long term CO_2 fumigation experiments under actual growing environments (Ruhil et al. 2015). However, due to the procedural complications, the key constituents of ecological unit responses to rising CO_2 often exist in out of prospect in such field experiments; the belowground structure of soil, roots, soil and linked microorganisms. Subsequently, the living root system is vital for the link of soil nutrient turnover to plant production, laboratory experiments particularly setup to mechanically linkage with the soil-root system, soil C and N turnover would be joined with field experiments.

The source of various ecological units' responses to rising CO_2 is most likely the plant since rising CO_2 secondarily affects soil carbon and nitrogen cycling by directly influencing plant growth. Consequently, much of the uncertainty adjacent soil C sequestration may be detached if we begin to recognize the causes behind wavering plant responses to rising CO_2. Up to now, results of some studies showed slightly consistent that C4 plants respond to a minor level to rising CO_2 over to C3 plants, which can be attributed to the various philological processes including photosynthetic pathways. Though, distinct response to rising CO_2 of plant species among these functional groups (C3 vs. C4) generally varies (Nowak et al. 2004). In attempts to predict plant species-specific responses to elevated CO_2, plants have been classified within broad groups, relying on a broad suite of related plant traits that can generalize how species respond to environmental changes (Eviner and Chapin 2003). For example, various experiments have been piloted using slow and fast-growing plant species with different life forms, for example, woody species over to herbaceous (García Palacios et al. 2015). Though, these taxonomies have not succeeded at finding a collective plant trait that can describe the variable responses of plants to rising CO_2.

The rising level of CO_2 elevated temperature and seasonal drought can affect soil microorganisms directly and indirectly (Williams et al. 2018). The variation in soil moisture with rising temperature can also have direct effects on belowground microorganisms. Thus, heating frequently has beneficial impacts some microbes including the nematode abundance (Blankinship et al. 2011) and impacts on the composition of other microbes (Allison et al. 2008). The limited rainfall has been found to reduce the abundance of various microbes such as; collembolan, enchytraeids and fungi (Blankinship et al. 2011). The CO_2 impacts on soil microbes are frequently unintended via plant responses such as the enhanced distribution of resources below the ground (Drigo et al. 2013). The rising CO_2 usually enhanced the total biomass of the microbes (Blankinship et al. 2011) and the richness of mycorrhizal-fungi due to increased plant-mutualism (Treseder 2004). In addition, the rising CO_2 had direct beneficial impacts on the soil moisture content, shoot biomass, microbial population and soil micro-arthropod taxa abundance (Eisenhauer et al. 2012). In another study, greenhouse experiment of grassland soil, the author found that CO_2 had a greater impact on increasing the population of trophic groups of nematodes including herbivores (30%) and bacterivores, and predators (110%); possibly for the reason that advanced trophic levels were controlled by resource constraint, although subordinate levels persisted inadequate by predation (Yeates et al. 1997). The meta-analysis of soil biota response to global change revealed that the rising CO_2 usually effects in an enhanced the population of microbes and their activity at the lowest of the food web, for example, protozoa and nematodes including bacteria, fungi, and micro-fauna (Blankinship et al. 2011).

Now a days, rising CO_2 will not happen unaccompanied but in combination with other climatic variations such as higher temperature and varied rainfall pattern. Subsequently, the responses of microbes to global variations are distinctive for every global variation element (Blankinship et al. 2011) and relations among various global variation element might generate responses not projected by single factor studies (Dam 2014), multi-factor studies are required. One of the little footage of multi global variation elements that effect soil microbe found important impacts including the rising CO_2, nitrogen deposition and seasonal drought (Eisenhauer et al. 2012). Now, the CO_2 was the global variation element disturbing most soil microbial groups, with enhancing richness at micro, meso and macro-fauna level. Additionally, CO_2 turned out to be the only global variation element playing a part when constructing a model of global variation impacts on the soil food web (Eisenhauer et al. 2012). The probable justification as previously given by Osler and Sommerkorn (2007) is that environmental change affecting the magnitude and quality of photosynthetic-C additions to the soil affects the soil microbiology that controls the soil C-cycle.

16.3 Impacts of Drought Stress

Under drought stress, the shoot and root growth is reduced due to the fact that plant homeostasis is regulated by ethylene endogenously (Glick et al. 2007). On the other hand, the bacteria that exist on the surface of roots contain ACC deaminase that helps the plant to modify the normal growth under drought by degrading the ethylene precursor ACC deaminase (Glick et al. 2007). The *Achromobacter piechaudi* has been shown to provide tolerance to tomato and pepper due to the activity of ACC deaminase under water deficit condition. Likewise, compared to non-inoculated plants, the ethylene production was decreased in inoculated plants showing improved recovery from low water condition (Mayak et al. 2004). Research on the effect of drought stress on the balance of plant hormone indicate an increase in abscisic acid (ABA) in leaves, showing decrease in endogenous cytokinin levels amplify ABA content, making stomata unsecure (Figueiredo et al. 2008; Cowan et al. 1999). The antagonism between cytokinin and ABA might be due to metabolitic interactions because they are showing a similar biosynthetic origin (Cowan et al. 1999). To know about the rhizobia nodulation or the plants ABA signaling, it would be more likely to find out the cytokinin produced by P. polymyxa (Timmusk and Wagner 1999; Figueiredo et al. 2008). When rhizobia face low water content during drought stress, it decrease the amount of nitrogen fixation. Similarly, when Rhizobium tropici was co-inoculated with two strains of P. polymyxa it enhanced plant height, dry shoot biomass and nodule formation (Figueiredo et al. 2008).

During water stress, the plants increased the cells osmotic potential as well as the osmolytes synthesis (Farooq et al. 2009) exudated by bacteria in the root zone. The drought tolerance is increased when the osmo tolerant bacteria synergistically produced Glycine betaine with plants in response to stress. Similarly, under severe stress condition, the inoculation effects of osmolyte producing bacteria on rice dry shoot and root biomass and number of tillers were more significant than the un-inoculated controls (Yuwono et al. 2005). Consistent with this, the osmo tolerant bacteria have the ability to produce IAA because under drought stressed rice this hormone has improved root proliferation (Yuwono et al. 2005).

Under drought stress, inoculation of maize seedlings with *Azospirillum brasilense* showed better absolute and relative water contents as compared to that of uninoculated treatments. Similarly, bacterial inoculation has been found in improving total aerial biomass, root growth, foliar area as well as accumulation of proline in leaves and root during low water condition. Compared to 50% reduction, these effects on growth parameters were higher at 75% reduction (Casanovas et al. 2002). Under deficit water, higher mineral contents (Mg, K and Ca) and reduction in grain yield losses of wheat were observed after inoculation with *Azospirillum* (Creus et al. 2004). Likewise, the relative water content, water potential, increases in water content as well as apoplastic water were also measured. Consequently, elastic adjustment and a better water status is thought to be important in increasing drought tolerance (Creus et al. 2004). Improving plant tolerance to drought and bringing about changes in its root morphology is widely thought to be due to inoculation of *Azospirillum.* Although the exact changes in root morphology in the presence of bacterium inoculation is not well known but it is believed that this process is enhanced by the bacterium producing hormone like substances that help in activating the levels of endogenous hormones (Cassan et al. 2001). Furthermore, recently it has been documented that during the adventitious root improvement the *A. brasilense* produces a considerable quantity of nitric oxide that take action as a signalling molecule in stimulating IAA pathway (Molina-Favero et al. 2008).

The agricultural productivity is mostly affected by the widely extended drought that is considered as one of the important effective natural calamity (Gornall et al. 2010; Lesk et al. 2016) and due the wide and global climate change the increasing events and intensity of drought can be predicted for the future from the current established environmental models (Lesk et al. 2016). Generally, during drought stress and arid soils having precipitation gradient (Bachar et al. 2010) a reduction in the total bacterial biomass has been observed (Alster et al. 2013) due to shortage of resources (Khan et al. 2016). It is also observed that due to the continuous exposure of bacteria to low water content (Hueso et al. 2011) or changing its functional potential (Bouskill et al. 2016), the biomass of bacteria under drought raminas stable (Hartmann et al. 2017) or shoot up (Fuchslueger et al. 2014). A proper explanation for the increasing or decreasing trend in soil bacterial biomass is still not well explained, meanwhile to study the soil microbiome community diversity is of another phenomenon where we can easily explain that the huge diversity of these microbes is beneficial for the overall soils and it is because the presence of high number of rich species predict more metabolic activities and greater decomposition of organic matter and efficient nutrients availability in the soils (Nautiyal and Dion 2008). The overall impacts of drought on bacterial phylogenetic diversity within the soil community is less (Armstrong et al. 2016; Tóth et al. 2017) and therefore this trend might be dependent on the drought pattern because in one of the studies 40% reduction in phylogenetic alpha-diversity was observed when the plots were exposed to drought in comparison to some pre exposed plots (Bouskill et al. 2013). Generally, with drought pattern the difficult factor that take part in inconsistency is the requirement of proper consistency for the drought treatment. The drought stress to soil have been imposed in a variety of ways including rain for different time periods (Yuste et al. 2014; Tóth et al. 2017) observing samples in a precipitation gradient (Bachar et al. 2010) as well as analyzing samples within drought and non drought time periods (Acosta-Martínez et al. 2014).

Apart from microbial diversity, serious impacts of drought stress have also been reported for community composition. The observed change in soil microbial community due to drought may be the change in relative abundance instead of complete abolition and therefore it give proper detail for any transformation in alpha diversity. Under drought stress, a broadly noticed events is the increased community and ratio of Gram negative than Gram-positive bacteria (Fuchslueger et al. 2014, 2016; Chodak et al. 2015). The change in relative abundance of some bacteria have been observed under low moisture containing soils. For example, under drought a reduction in the Gram-negative includes Verrucomicrobia, Bacteroidetes and Proteobacteria (Barnard et al. 2013; Acosta-Martínez et al. 2014; Yuste et al. 2014) while an enhancement in Gram positive include Actinobacteria and Firmicutes (Bouskill et al. 2013; Hartmann et al. 2017).

Often these changes in relative abundance are driven by one or a few members of a phylum, as seen in Barnard et al. (2013); while relatively few groups had a large magnitude of change, most bacterial groups only had small shifts in response to drought. An experimental reduction of precipitation in German forest ecosystems provoked an increase of 300% for the family Micromonosporaceae, which was far more than its parent phylum Actinobacteria (Felsmann et al. 2015); another study found increases in Actinobacteria that were mainly attributable to members of order Actinomycetales (Bouskill et al. 2013).

16.4 Impacts of Temperature Stress

Soil is the naturally occurring physical covering of the earth's surface that represents the interface of three material states: solids (geological and dead biological materials), liquids (water) and gases (air in soil pores). Soil is the foundation of all terrestrial ecosystems and is home to a vast diversity of microorganisms like bacteria, archaea, fungi, insects, annelids, and other invertebrates as well as plants and algae.

Soil microbes including bacteria, archaea and fungi play diverse and often critical roles in the ecosystem services. The vast metabolic diversity of soil microbes means their activities drive or contribute to the cycling of all major elements (C, N, P) and this cycling affects the structure and the functions of soil ecosystems as well as the ability of soils to provide services to the people. Microorganism are biochemically involved in the turnover of elements through two main processes like immobilization and mineralization (Torsvik et al. 2002; Crawford et al. 2005). Plant growth is largely dependent on the availability of inorganic nutrients provided by biomineralization, so understanding nutrient cycling in soils under a variety of conditions is of major importance.

Current climate changes are leading to an increase of high temperature events (Stocker et al. 2013) and misuse of soil capabilities and poor management of vegetation can lead towards desertification and formation of arid or semi-arid soils. Soils with poor or highly reduced plant cover are exposed to intense solar radiation which leads to increasing temperatures at the upper soil layers. Altogether, these factors lead to soil temperature values well above the optimum for commonly studied mesophilic soil bacteria; values above 40 °C are frequently observed with measurements reaching 75 °C (Portillo et al. 2012a, b; Gonzalez et al. 2015) and some investigators have reported temperatures higher than 90 °C in deserts (McCalley and Sparks 2009). As a consequence, microbial activity at upper soil layers (the outermost layer of soil, usually the top 5 cm in our study) has been suggested to be highly reduced during such extreme temperature events, similar to animals and plants inhabiting these soil zones (Townsend et al. 1992; Conant et al. 2011).

Like other organisms, microorganisms are very sensitive to temperature changes and in other forms, temperature is a key limiting factor. It must be kept in mind that each species and often each strain has its own minimum, optimum and maximum temperature and the interactions with other factors occur in the field, which may induce alteration of the response curve to temperature. Moreover, when symbiotic systems are dealt with, one should take into account the effect of temperature on each of the partners and on the association itself. In his recent review, Gibson (1977) draws the attention to the possibility of compensation by the symbiotic legume system for adverse effects of moderately low or high temperatures. For example, under moderately to high temperatures nodule numbers and/or nodule weight may be higher than under optimum temperature conditions. The greater volume of bacteroid tissue formed under these conditions is interpreted as resulting from the ability of the system to compensate for unfavorable temperature conditions.

Some cases of potential activity by mesophilic bacteria have been reported at temperatures above 40 °C (Gonzalez et al. 2015) or after exposure to these temperatures as a result of metabolic stimulation (Ho and Frenzel 2012) or germination of resting cells (Whittenbury et al. 1970). In general, mesophilic bacteria undergo a decline in activity and survival period under high temperature events although other microorganisms, adapted to these high temperatures, may succeed in finding suitable temporal conditions to develop. Recent reports have highlighted the occurrence of peaks of enzymatic activity at high soil temperatures (in the 55–75 °C range) (Gonzalez et al. 2015) and the ubiquitous presence in all tested soils of thermophilic bacteria, specifically species belonging to Geobacillus and related genera (Marchant et al. 2002, 2008; Portillo et al. 2012a, b; Santana et al. 2013). These thermophiles exhibit optimal growth between 50 and 70 °C under laboratory conditions. In addition, these thermophilic bacteria are mostly present in temperate soils as vegetative viable cells (Marchant et al. 2008; Portillo et al. 2012a, b) which strongly suggest that they can be potential participants of soil biogeochemical reactions (Gonzalez et al. 2015). Therefore, the study of these soil thermophilic bacteria and their role in soil ecosystems is an aspect deserving further consideration.

Temperature is one of the most important factors influencing soil organic matter decomposition and microbial communities. For example, temperature significantly affects the soil microbial phospholipid fatty acid composition associated with straw decomposition at the early stage (Zhou et al. 2016). Bacterial abundance increases in conditions of elevated temperature and CO_2 concentration (Castro et al. 2010). The complex responses of bacterial composition and diversity of bamboo soils across altitudinal gradients have been suggested to result from interactions with multiple factors, including temperature (Lin et al. 2015).

Soil bacterial communities include different phylotypes that likely represent different functional groups, and their relative abundances are affected by carbon (C) availability. For example, some members of Proteobacteria are considered copiotrophs, and their relative abundances appear to be higher in C-rich environments. In contrast, oligotrophs (e.g., Acidobacteria) can live in stressful environmental conditions (Fierer et al. 2007). However, little is known about how these two groups respond to the environmental temperature changes. Here, we hypothesized that the temperature changes would alter the structure and diversity of soil bacterial communities at different elevations, and that bacterial taxa, including copiotrophic and oligotrophic groups, would have distinct responses to altered nutrient availability caused by temperature changes.

The microbial decomposition process of soil organic matter is highly sensitive to such change in surrounding environmental condition (temperature increase) which has the potential to modify the enzyme kinetics and associated nutrient availability in the soil system through alteration in resource allocation strategy and community composition of the soil biota (Stone et al. 2012; Steinweg et al. 2012). The modified dynamics of soil microbial activity in warmer environment may determine the effective direction and net magnitude of C flux among the source-sink components of global carbon cycle as well as the status of soil C pools, available nutrient status and the soil C stock that ultimately affect the crop production (Majumder et al. 2008; Wall et al. 2013). In courtesy, Mganga et al. (2016) observed that the traditional agroforestry systems promoted soil fertility with enhanced soil microbial biomass C and associated enzyme activities, than the monocropping with agricultural crops (maize) for the soils of natural to slightly acidic soils of tropical Africa. The beneficial role of minimum disturbance in different land use systems enhanced soil enzyme activities involved in C, N, P, S cycling Acosta-Martínez et al. (2007) that resulted the increase net nutrient availability for acid soils in different land use systems (orchards, grasslands and agricultural crops) of subtropical China Liu et al. (2010).

However, many of the studies on temperature sensitivity do not take into account the effects of the natural soil micro-environment and microbial community, which are often severely disturbed in artificial field and laboratory experimental warming experiments (Bradford et al. 2010; Thomson et al. 2010). Respiration/soil C was highest for soils from high native temperatures. Increased nitrogen (N) mineralization and microbial enzyme activity in soils from high native temperatures shown here have the potential to mitigate soil C losses by increasing allocation of C into plant and microbial biomass. However, this effect may not be sufficient to offset the larger potential losses of C in soils from low native temperature sites. This suggests that soils from low native temperatures have a greater potential to release C over time, since C stocks in these soils are not depleted as quickly as are carbon stocks in soils with high native temperature sites. Increased temperature-induced respiration combined with large soil carbon stocks and low N mineralization rates may make soils from low native temperatures regimes more likely to further increase atmospheric carbon dioxide levels.

Forests ecosystems account for approximately half of the Earth's terrestrial surface and their responses to increased temperature are of great concern (Dixon et al. 1994). The amount of carbon dioxide (CO_2) respired from all soils is over 11 times larger than the CO_2 pumped into the atmosphere via anthropogenic processes (Bader and Korner 2010) and forests account for approximately 40% of global soil C (Dixon et al. 1994). Increasing global temperatures can induce greater soil respiration (Bond Lamberty and Thomson 2010), and the potential for a positive feedback between soil carbon (C) release and temperature remains unclear (Campbell et al. 2009; Bader and Korner 2010). The fate of soil C is therefore of paramount importance for projected climate change scenarios. The distribution of this C stored in soils will also affect potential mineralization of soil C since climate change is variable at regional scales (CCSP 2007; Christensen et al. 2007).

A greater respiration/soil C indicates that more of the available substrate was being used for microbial metabolism when cores were incubated at higher temperatures in the laboratory. In general, we observed an increase in dehydrogenase, fluorescein diacetate hydrolase and β-glucosidase activities with increase in incubation temperature. Dehydrogenase and fluorescein diacetate hydrolase represent microbial activities in general, while β-glucosidase is a carbon degrading enzyme involved in carbon depolymerization. The probable reason of increase of these enzyme activities may be due to increase in the substrate (e.g. microbial biomass) availability at elevated temperature (Joergensen et al. 1990). On the contrary, the decrease in acid phosphomonoesterase and aryl sulphatase activities may be due to their denaturation at higher temperature.

16.5 Impacts of Soil Moisture Stress

Soil moisture is a crucial variable that has a significant role in managing the patterns of soil respiration and hence decomposition of soil organic matter in ecosystems (Aanderud et al. 2011). In soil several process like water movement, gas, and solute diffusion as well as survival and motility of microorganisms are controlled by soil moisture (Rodrigo et al. 1997; Luo and Zhou 2006). Moisture can also overwhelm microbial activity in several environments such as salt water and soils. Moisture stress reduces intracellular water potential and thus decreases enzymatic activity and hydration (Stark and Firestone 1995). Aanderud et al. (2011) also documented that, soil moisture have intense effects on the dynamics and emission of CO_2. According to Aanderud et al. (2011) in grasslands, soil moisture and temperature mainly control soil respiration, correspondingly, determines carbon dioxide (CO_2) flux between soils and air.

Very often, temperature changes are combine with fluctuations in soil moisture, which may explain some unpredictable results from experiments exploring how microbial communities respond to climatic change. Such as, rates of microbial activity decrease at warmer temperatures by diffusion and microbial contact with available substrate (Zak et al. 1999). Whereas bacterial communities may react quickly to moisture changes and the slower-growing fungal community may respond slowly (Bell et al. 2008; Cregger et al. 2012, 2014). Additionally, drought intensifies the differential temperature sensitivity of fungal and bacterial groups (Briones et al. 2014). Even as mall changes in soil moisture may shift fungal communities from one dominant member to another but may not affect bacterial communities. Though, it is still uncertain that (1) how temperature, moisture and their interaction, affect specific microbial functional groups, such as methanogens, within a community; (2) what is the effect of changes in microbial community decomposition of fresh and old soil organic matter; and (3) which mechanisms drive the net ecosystem response of microbial activities to climate change.

Climate models have projected un even pattern of rain fall for many regions of the world (Jentsch et al. 2007; IPCC 2013) which is expected to increase abiotic and biotic stress on plants (Jentsch et al. 2007; IPCC 2013). Furthermore, indirect impact of climate change like nutrient availability and soil microbial community composition may also occur, both of which affect plant growth (van der Heijden et al. 1998; Bardgett and Wardle 2010).

These indirect effects can result in the establishment of “soil moisture legacy effects” where plants are impacted by conditions prior to plant establishment (Meisnera et al. 2013). Plants have evolved many strategies and traits for optimizing nutrient acquisition (Lynch 2007), including the formation of arbuscular mycorrhizas (AM) (Lambers et al. 2008; Smith and Read 2008). In poor soils the formation of AM can improve plant fitness and competitiveness, which has significant contribution in ecosystem productivity and biodiversity (van der Heijden et al. 1998; Facelli et al. 1999; Cavagnaro et al. 2004). The adverse effect of soil moisture legacy effects may be a poor root colonization by AMF. Furthermore, if soil moisture legacy effects induce nutrient deficiency (e.g. via stimulation of denitrification under wet conditions leading to gaseous soil N loss), the relative benefit of forming AM may be higher. In contrast, if soil moisture legacy effects nutrient availability (e.g. via stimulation of mineralization N and P), the role of AM may be diminished. Interactively, adverse effects of soil moisture legacy on AM may be a change in the balance between the costs and benefits of forming AM, with shift from negative, neutral or positive mycorrhizal responses resulting (Johnson et al. 1997). Since most plants form AM, and these associations can have a vital role in improving growth and nutrition of plant. Soil moisture legacy significantly effect on the formation and functioning of AM. Here, are presented a result which shows the response of AM, to changing soil moisture. The experiment involved growing a mycorrhiza defective tomato mutant, and its mycorrhizal wild type progenitor (Barker et al. 1998) in soils with (experimentally established) different soil moisture legacies. This genotypic approach for controlling the formation of AM was selected as it allows for the comparison of mycorrhizal and non-mycorrhizal plants with the wider soil biota intact (Rillig 2004; Watts- Williams and Cavagnaro 2015), and because the two genotypes exhibit very similar growth patterns when grown in the absence of AMF (Watts-Williams and Cavagnaro 2014).

Climate change rainfall pattern throughout the world (IPCC 2014). Globally, a deviation of rainfall patterns is documented in mid latitudes (having dry regions), subtropics having low rainfall and higher latitudes receiving abundant rainfall Due to these changes, severe rainfall events are expected to happen in the current century in the nearer future specially in Asia and Eastern Africa, North America, Northern and Central Europe (IPCC 2012, 2014). In different regions of the world including South Africa, Mediterranean, Central America, the Amazon and North East Brazil more longer and dry spells have been documented In several terrestrial ecosystems, the changes brought about by precipitation and temperature that affect evaporation will definitely bring changes in soil moisture and consequently will bring extended water logged conditions after severe flooding and rainfall. These changing events will affect the plant microbe interaction, plant growth, water patterns, the soil flora, fauna and microbial activities as well as the fungal hyphal growth directly and indirectly it may affect the plant microbe interaction by altering the plant chemistry. But on the other hand, the dry conditions will lead to stomata closure, which consequently affect the carbon assimilation and as a result the plant growth is reduced. Due to plant growth under stress conditions the abundant carbon is stopped and may cause increase in the chemical compounds (carbon based) like phenols and tannins that become a threat to herbivores and several decomposers (Herms and Mattson 1992).

In waterlogged condition, oxygen is depleted from soil pores which bring about changes in different physico-chemical properties of soil and ultimately lead to plant damage. The toxic ions and fermented materials become poisonous to plant fine roots that restrict the carbohydrates and energy for proper plant growth and metabolism and therefore the whole plant is affected finally (Colmer and Voesenek 2009).

The metabolic and growth changes not only damage the symbiotic relationship between organisms and plant roots but also affect the presence and quality of food supply to decomposers, pollinators and herbivores. Moreover, the change in populated species of the plant community may have more intensive effects on close partner because the species disrupted in stress condition can also affect the particular plant partners as well the overall chemical composition of plants is also affected due to community shifts. The Autecological species are also changed due to different moisture regimes, and these changes may be in plant biomass (Ciais et al. 2005; Jentsch et al. 2011), species distributions or migration (Harschand et al. 2016) that have been properly managed in the last decades, with an intention on a strong edge on the cause of drier soil moisture conditions. Still there is a lack of research studies plant microbe and microbe microbe interaction in in reaction to change in soil moisture conditions (Tylianakis et al. 2008). It has also been reported that the interactions of species may reverse or even override the autecological responses (Angert et al. 2013; Trzcinski et al. 2016) and that the species interactions with each other strongly affect the stability and diversity of ecosystem (Bascompte et al. 2005). Tylianakis et al. (2008) reported that most of the symbiotic interactions specially with plants will be affected by global change, but not only CO_2 enrichment and concluding all other climatic phenomenon, not suitable for a detailed opinion about the effects of changed soil moisture.

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Chapter 17
Measuring Vulnerability to Environmental Hazards: Qualitative to Quantitative

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Abstract Recently environmental hazards are occurring very frequently over the globe and a great concern for the society owing to its high rate of vulnerability. Measuring vulnerability to environmental hazards poses an immense challenge for disaster risk relief efforts in the world. For the effective application of vulnerability reduction as well as mitigation actions, it is necessary to quantify the level of vulnerability. Using multiple dimensions of vulnerability is correspondingly important to identify the vulnerable community and places. In this study a framework is proposed for measuring vulnerability to environmental hazards quantitatively. The proposed framework measures vulnerability by identifying and evaluating the respective dimensions of vulnerability with numeric scoring technique. The vulnerability

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_17

dimensions cover all the factors (exposure, susceptibility and resilience) of vulnerability to environmental hazards. It defines vulnerability in a quantitative scale yclept vulnerability score of each dimensions of vulnerability. Considering the features of the previous qualitative vulnerability frameworks, the present framework has been developed. Moreover, this quantitative vulnerability measuring framework for environmental hazards is introduced on the basis of numeric score. Thus, the proposed framework might be applied for assessing vulnerability within a community, regional and national level. It can also be exploited as a supporting tool in decision-making process, planning, crisis management, disaster reduction and mitigation to environmental hazards.

Keywords Environmental hazards · Vulnerability · Disasters

17.1 Introduction

Due to the global environmental variation and fast economic as well as social growth human being are facing numerous threats from natural along with manmade disasters (Bouzelha et al. 2018; Gautam and Dong 2018; Nagy et al. 2019; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). However, although vulnerability is being discussing as an important theoretical topic for more than three decades, but practically the term vulnerability is emerging from last few years (Adger 2006; Chen et al. 2019; Mavhura et al. 2017). Measuring vulnerability is the most important key component of disaster management and plays a vital role to promote safety for human society. Various organizations and researchers have done comprehensive investigations on vulnerability measurement. In addition, several models and approaches have also been manifested and applied for vulnerability measuring (Shi et al. 2010; UNISDR 2015). Most of the existing vulnerability measuring frameworks employ either qualitative

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or semi-quantitative methods. These can only be used to compare the vulnerability level between regions. However, a quantitative vulnerability framework symbolizes the likelihood of disaster damage which helps the decision makers for perceiving disaster risks (Fakhruddin et al. 2019; Ming et al. 2015; Zakour and Swager 2018). Recent studies promote paradigm shift from the qualitative vulnerability measuring to quantitative vulnerability measuring (Chen et al. 2013; Dintwa et al. 2019). Therefore, to measure vulnerability quantitatively it is required to understand social, political, and economic background deeply and after that address the factors, those increase vulnerability.

Recently, several studies (Aroca-Jiménez et al. 2018; Birkmann 2006; Chen et al. 2013, 2019; Fatemi et al. 2017; Ismail-Zadeh et al. 2018; Ming et al. 2015) concerning vulnerability measurement to environmental hazards have been performed across the globe. These studies covered both qualitative and quantitative vulnerability measuring. The measuring of qualitative vulnerability methods are mainly focused on qualitative analysis of the environmental hazards (Cardona 2013). Generally, it can be expressed that the expected losses is defined qualitatively of certain hazard in a specified area (Ehrlich et al. 2010). Whereas, in quantitative vulnerability analysis, a truly integrated functional framework of all factors and dimensions of vulnerability is essential. Ismail-Zadeh et al. (2018) showed in their study, how vulnerability measuring can contextualize for the geohazards and analyzed the vulnerability of earlier and existing geohazards qualitatively. By involving local knowledge and capacities they revealed how a qualitative vulnerability measuring approach might be applied for decision-making as well as adaptation in local level to increase resilience and decrease vulnerability. Barua et al. (2016) introduced an integrated framework to assess socio-economic vulnerability for flood hazards (Huq 2013). They pointed out how the direct and indirect factors are responsible to create vulnerability and asses the social vulnerability as well. They revealed the significance of measuring social vulnerability (Barua et al. 2016). By analyzing physical and social vulnerability, Fatemi et al. (2017) built a bridge in-between the scholars from science and humanity and analyzed vulnerability context comprehensively. The authors conclude that in terms of environmental hazards, well social networks, strong economic and institutional settings as well as political factors help to reduce vulnerability stress substantially.

The identification of vulnerability dimensions is a critical part in coherent disaster management. Though so far, mostly it has been ignored in the respective academic attempts (Muller-Mahn 2012). Understanding of the patterns of quantitative vulnerability, geographical boundaries of their trigger, as well as the formation of appropriate framework is important to manage a disaster effectively (Aubrecht et al. 2013; Shao et al. 2019a). Vulnerability measuring helps to recognize the susceptibility (Huq and Hossain 2015; Kulkarni et al. 2014). Vulnerability measuring methods and techniques should be modest, logical, reasonable and applicable for decision-making process (Birkmann 2005). However, numerous methods, frameworks and models have been introduced, but those are not feasible for all regions of the world. This study attempts to overcome this problem by introducing a quantitative framework to measure vulnerability for environmental hazards. This paper firstly presents the theoretical background related to environmental hazard, disaster, and vulnerability. Then it discusses details about the dimensions of vulnerability and the processes of building the quantitative vulnerability framework to measure vulnerability quantitatively. The key novelty of the present study, in respect to existing literatures is to introduce a new framework that can measure vulnerability quantitatively. This unique method might be applied to develop a new framework for a given area and calculate the qualified vulnerability score.

17.2 Theoretical Background and Conceptualizations

17.2.1 Hazard

The concept of hazards originates from interactions between man and environment. A natural hazard is a combination of different physical processes and human activities that create a variety of disasters (Chang et al. 2018; Fakhruddin et al. 2019; Huq and Hossain 2012; Zakour and Swager 2018). In disaster management, the first step is to identify and profiling of hazards. However, according to Islam et al. (2013), hazards are events or physical conditions that have the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, environmental damage, interruption of business, or any other type of harm or loss. Moreover, hazards are those extreme events either natural or man-induce, which exceeds the tolerable magnitude within or beyond certain time limits, make adjustment difficult, resulting catastrophic losses of property, income and lives and become the headlines of different print and electronic media at international level (Anderson et al. 2019; Chen et al. 2016; Papadopoulos 2016; Pokhrel and Seo 2019). It is also considered as an extreme natural event with a certain degree of probability of having adverse consequences. It has been defined by UNISDR (2015) as environmental hazard (afterwards denoted as 'hazard') is a natural mode or phenomenon which might have negative consequences on the society. It is an object, behavior, or situation that may have potentiality to cause for injury and/or damage property and the environment (Islam et al. 2013; Shao et al. 2019b). Environmental hazard is defined as a threat potential for human or nature with the incidents originating in, or transmitted by the natural or built environment (Chang et al. 2018; Ming et al. 2015; Papadopoulos 2016; Ujjwal et al. 2019). An environmental hazard might consider as the geophysical occurrence and when it happens in extreme way with the involvement of human factors that may put forward a disaster (Hagenlocher et al. 2018). Finally, hazards could be defined as the unexpected situation for human and physical environment. It causes fatalities, injuries as well as damage to social and economic attributes. The Fig. 17.1 illustrates a spectrum of hazards.

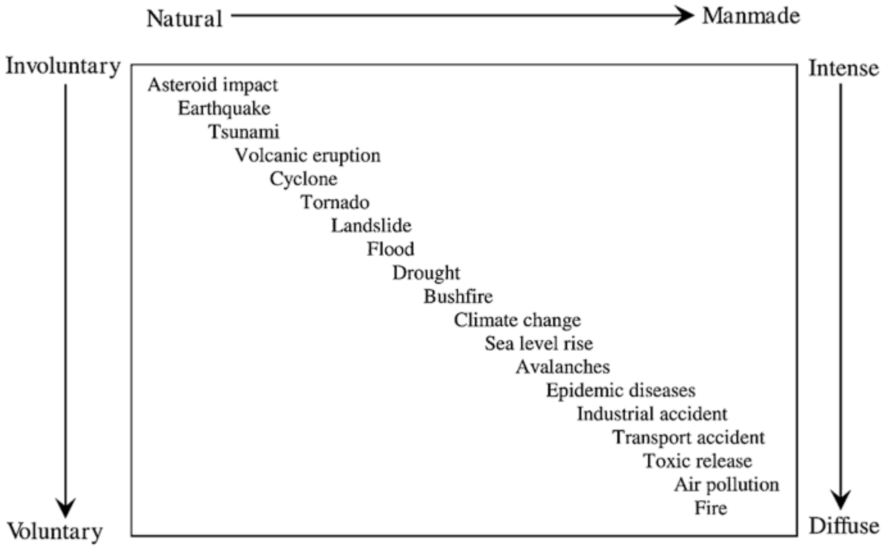

Fig. 17.1 A spectrum of hazards

17.2.2 Hazard to Disaster

Disasters are social phenomenon that occurs when a community suffers special levels of disruption and face losses due to natural or human processes. A hazard event can strike an uninhabited region, but a disaster can exist only where people and process related with them exists (Coppola 2006). There is no specific definition of disaster but some studies have tried to define disaster based on specific circumstances. It is an event, natural or man-made, sudden or progressive, which process impacts with such severity that the affected community has to respond by taking exceptional measures (Birkmann 2006; Chang et al. 2018; Coppola 2006; Ku-Mahamud et al. 2008; Manuta and Lebel 2005; Walters and Gaillard 2014). It concentrated in time and space that causes sufficient human deaths and material damage to disrupt the essential functions of a community and to threaten the ability of the community to cope without external assistance (EM-DAT 2014).

Hazards are the processes whereas the disasters are the results or responses of hazards. Hazards always create extreme events but not all the extreme events become disasters. Hazards are the processes whereas the disasters are the results or responses of hazards. Hazards always create extreme events but not all the extreme events become disasters. Disaster generally originates from the interaction between the socioeconomic and physical exposure to a hazardous process and a vulnerable human population. A natural disaster is the adverse result of the impact of a natural hazard on human socioeconomic system. Disasters are now increasing rapidly because of cumulative risk processes, poor land-use practices, development projects, lack of rules and guidelines etc. Social, economic and environmental conditions are considered as responsible factors for aforementioned causes. It is a complex process and mostly beyond the limit of human capacity to control it (Ma et al. 2020). The timing of hazards is unlikely to be forecast or an intricate process to announce the correct temporal and spatial scale for them. All kinds of hazards occur randomly. Turning into a disaster from a hazard depends upon magnitude and frequency of hazards (Fig. 17.3). When a hazard occurs frequently with a high magnitude then it transforms into a disaster (Islam et al. 2013). A disaster is measured with human terms (lives lost, people affected, and economic losses) which are the outcomes of any hazard. Berrouet et al. (2018) argue that in short time scale, focus should be on designing a system for prediction and early warning, while in the longer time period emphasis should be put on prevention and mitigation of natural hazards and adaptation for future planning. If the activities could not achieve these conditions then a hazard obviously turns into a disaster (Berrouet et al. 2018). There is another reason responsible for disaster. That is power of resilience. For example, an earthquake can easily disrupt infrastructure like road networks, electric lines or water systems. If the affected community can recover it instantly then it will not turn into disaster.

17.2.3 Vulnerability

The notion of vulnerability is originated from the field of natural disasters (Timmerman 1981) and increasingly employed in various research fields (Chen et al. 2019; Johansson and Hassel 2010). Vulnerability causes damages to lives, assets and livelihood by any kinds of hazard or disaster that means vulnerability represents the system of community's physical, economic, social or political susceptibility to damage as the result of hazardous events (Cardona 2013; Huq 2017). The concept of vulnerability within the disaster management context are too complex and varied. In general, it refers to the susceptibility of a community to get harm from an event, often determined by a community's geographical exposure (Adger 2006; Etkin 2016; Papadopoulos 2016; Pokhrel and Seo 2019). However, presently, there is no acknowledged definition of vulnerability, and typical vulnerability concepts in different time periods are presented in Table 17.1.

Vulnerability is argued in the present study as a degree of threat that might happened within particular circumstances of exposure, susceptibility and resilience. Considering the different previous concepts of vulnerability, the following equation of vulnerability could be formulated:

$$\begin{aligned} Vulnerability &= xposure + Susceptibility \\ &\quad - Resilience\left(Balica\ and\ Wright\ 2010\right). \end{aligned} \tag{17.1}$$

Table 17.1 Typical vulnerability concepts in different time periods

Sources	The notion of vulnerability
Timmerman (1981)	Vulnerability is a degree of the system that may have negative effects after a hazard/disaster of event.
Dow (1992)	Vulnerability is an ability of a society or groups for coping with disasters, as well as the ability stems of their condition in natural or social environment.
IPCC (1992)	Vulnerability is a degree of inability for coping with the impacts of the climate change as well as sea-level rise.
Einarsson and Rausand (1998)	Vulnerability describes the properties of a system that might weaken its ability for surviving and performing its mission with the existence of threats.
IPCC-TAR (2001)	Vulnerability is a degree, by which a system is susceptible to, or incapable to cope with, negative effects of the climate change. Vulnerability = risk (projected negative climate influences) – Adaptation
Alwang et al. (2001)	Vulnerability is the function of susceptibility and resilience along the level of knowledge.
Turner et al. (2003)	Vulnerability is a degree of damage of a system, subsystem or system component caused by exposure of hazard, perturbation or stress.
Cutter et al. (2003)	Vulnerability is considered as the hazard of a place that includes biophysical risks along social response and action.
Bogardi et al. (2004)	Vulnerability means predisposition of properties, people, structures, infrastructures, and human activities to damage with low resistance.
Aven (2007)	Vulnerability is the deficiency or weakness that decreases a system's capability to survive with threat or recommence a new permanent condition.
Johansson and Hassel (2010)	(i) Vulnerability is known as a universal system property which reveals the level of unfavorable effects triggered by an occurrence of a certain hazardous event; (ii) vulnerability is applied to describe the components or features of a system.
Tapsell et al. (2010)	Vulnerability is a condition discerned by the social, economic, physical, as well as environmental features or processes that raise the defenselessness of a society to the consequences of hazards.
Wisner (2010)	Vulnerability symbolizes the potentiality of loss along two sides ① an exotic side of strokes and perturbations, these expose a system, ② an inner side that characterizes the capacity and lack of capacity to effectively respond as well as recover from exotic stresses.
Berrouet et al. (2018)	Vulnerability denotes the degree of a system's function loss when the system is badly oppressed by the various kinds of hazards, which is inversely proportionate to system's resilience.
Nagy et al. (2019)	Vulnerability is the tendency or predisposition of the assets to be adversely affected by hazards. It incorporates exposure, sensitivity, possible consequences, and adaptive capability.

17.2.4 Linking Hazard, Disaster with Vulnerability

The different terminologies (e.g., hazard, disaster, vulnerability, exposure, risk etc.) used in the field of natural disaster study have not been accepted yet universally (Dintwa et al. 2019). However, the following equation demonstrates the relation among the three components: hazard (H), disaster (D), and vulnerability (V):

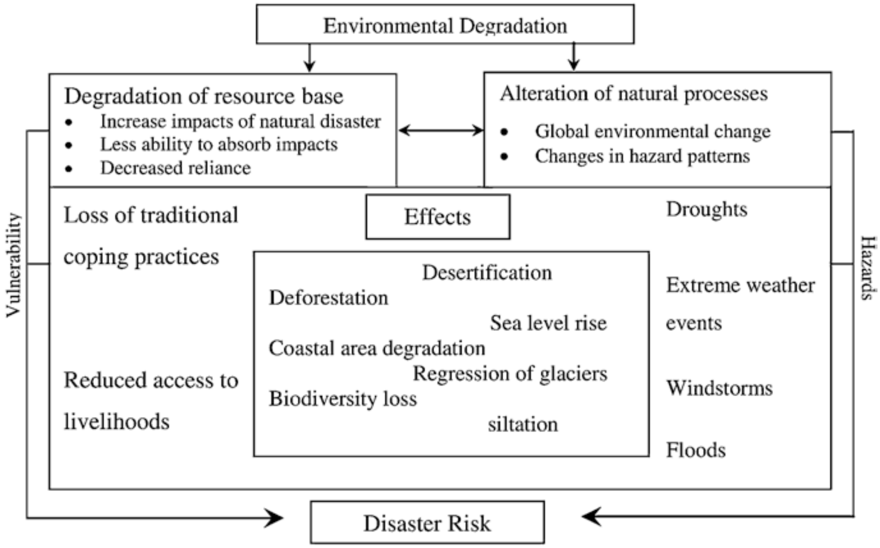

Fig. 17.2 The linkages among environmental degradation, natural hazards, disasters, and vulnerability (UN/ISDR 2006)

$$Disaster(D) = Hazard(H) + Vulnerability(V). \tag{17.2}$$

Natural environment of a country or community has a great role in hazard or disaster vulnerability. For example, natural environment of the Bangladesh makes it as a flood prone (Barua et al. 2016) country but it is not applicable to other countries of the world. The linkage between environmental degradation, natural hazards, disasters, and vulnerability has been developed by UN (Fig. 17.2).

17.2.5 Vulnerability Factors

The identification and understanding of vulnerability and its underlying factors are important (Brooks 2003; Cutter et al. 2003; Hagenlocher et al. 2018; Nagy et al. 2019). Corresponding measurable factors cover structural, economic, social, educational, political, institutional, cultural, environmental, ecological, climatic, and ideological dimensions (Adger 2006; Ahsan and Warner 2014; Anderson et al. 2019; Pokhrel and Seo 2019; Villagrán de León 2006; Walters and Gaillard 2014).

All these characteristics of vulnerability could be related to natural disasters. Dunno (2011) has identified six factors of vulnerability. Those are poverty, livelihood, cultural beliefs, equity, gender and worker social groups. On the other hand, Balica and Wright (2010) described that, vulnerability of environmental hazards consists of three factors (i.e., exposure, susceptibility and resilience) (Fig. 17.3).

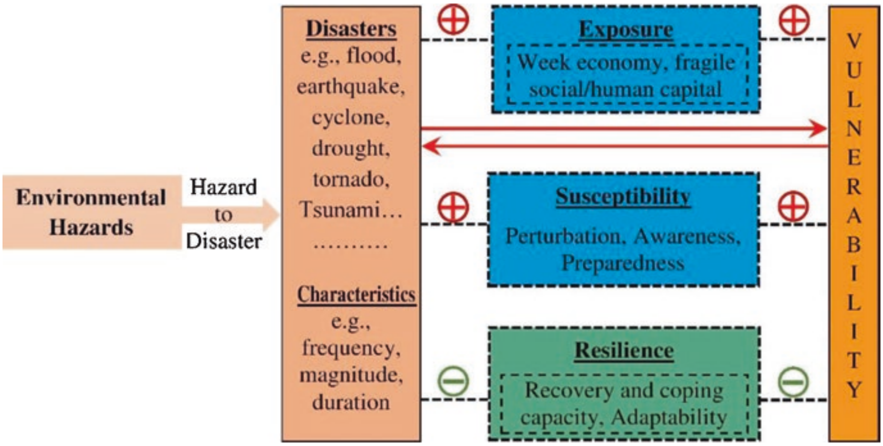

Fig. 17.3 Hazard to disaster system and factors of vulnerability (modified from Balica and Wright (2010))

These factors are influenced by four main dimensions, including social, economic, environmental and structural. Moreover, these components accelerate the vulnerability system. Societies are vulnerable to hazards owing to three key factors (e.g., exposure, susceptibility and resilience) (Baum et al. 2008). More particularly, in hazardous situation, a system becomes susceptible to disasters because of exposure and recovers or adapts or cope with the extent by its capacity (resilient) (Gautam and Dong 2018).

Exposure is the principal factor of vulnerability. It refers the level or extent of a system influenced by perturbation (Adger 2006). It has been identified as human, belongings, systems, and other components exist in hazardous zones those are thus subject to probable losses. It is defined as the prospect that people and/or natural substances might be affected by hazards (Chen et al. 2016). It may be realized as values those are appeared at that location where hazards might occur. These values could be properties, infrastructure, cultural inheritance, agricultural lands and people (Shi et al. 2010).

Susceptibility is related to the system characteristics that includes social situation of losses owing to disaster, specifically public awareness as well as preparedness pertaining the risk (Baum et al. 2008; Fatemi et al. 2017; Pokhrel and Seo 2019). The capability of people and community systems to manage the effect of disaster is mostly linked with the overall socio-economic condition. However, susceptibility is referred as the components those are exposed inside a system and influences the likelihoods of damage in hazards (Muller-Mahn 2012). The elements of susceptibility include social relationship, institutional improvement and population (Zakour and Swager 2018). Moreover, it refers the response skill of the internal as well as external perturbations that typically relies on the physical strength of a hazard-affected bodies (Ehrlich et al. 2010).

Resilience denotes the capacity of a system, community or group to resist, adopt, accommodate and reclaim from the impacts of hazards timely as well as efficiently, including reclamation of its vital infrastructures and functions (Aubrecht et al. 2013; Bouzelha et al. 2018; Chen et al. 2013; Ismail-Zadeh et al. 2018). It is evaluated by the political, administrative, economic, environmental, and social situation. The response, coping and adaptive capability are the key elements of resilience, those reflect the capacity to defend or recover from the damage (Adnan et al. 2020). Response and coping capacity are the short-term activities taken by a system to protect perturbation damages of disaster. It is the defense capability and coping capacity of the environmental disasters. It is a capacity and/or ability of the adjustment of disaster, that mostly manifested in absorption and recover the environment (Gautam and Dong 2018).

17.3 Dimensions of Vulnerability

17.3.1 Environmental Vulnerability

The existing level of environmental degradation is one of the particular relevant factors to evaluate vulnerability of hazards. The effects of environmental degradation might vary with climatic conditions. The environmental sphere cannot be separated from the social and economic spheres because of the mutuality between human beings and the environment. Several existing vulnerability frameworks incorporate environmental components (Ahamed 2013; Altan et al. 2013). Direct impact on vital resources (e.g. water, soil), environmental degradation increases the vulnerability of communities (Dewan et al. 2005). Environmental vulnerability represents the vulnerability of both natural and manmade hazards. It includes biological, climatological, geological, as well as anthropogenic aspects. The climate change, water, biodiversity, human health facets, and desertification are also considered as the environmental exposure and disasters. The criterion of environmental vulnerability is heterogeneous in nature (Ahmed 2016; Balica and Wright 2010; Birkmann 2005; Gibb 2018; Hinkel 2011).

Environmental vulnerability includes several issues. For example, geomorphic features, such as altitude and slope influence the surface water flow as well as land use in a great extent (Ehrlich et al. 2010). The vegetation reduction and soil erosion lead to elevated runoff ratio, interconnects surface with subsurface conditions (Balica et al. 2012; Huq and Alam 2003). Thus these characteristics increase the vulnerability to occur drought, flash flooding and geological hazards (Ming et al. 2015; Mohit and Akhter 2000). Extreme rainfall caused for soil erosion, debris movement, landslide, and various geological disasters, whereas drought hampers vegetation and crop development, hinders the agricultural, ecological and economic growth significantly (Duží et al. 2017; Saleem et al. 2019). Moreover, the climatic aspects (e.g., air, soil, water, temperature, rainfall) are also the leading factors for entire natural energy and ecosystem (Kamruzzaman et al. 2020). Additionally, wind velocity and sunlight hour are considered as the major climatic issues to assess environmental vulnerability (Johansson and Hassel 2010). However, the fact that, poor people tend to live in higher risky locations such as polluted areas with severe climate, which are relevant in determining vulnerability to epidemics (Sarker et al. 2020). In addition, the location and accessibility of drinking water has great importance for determining vulnerability (Olorunfemi 2011; Schneiderbauer and Ehrlich 2006). Vulnerability is not homogenous within any given area. It varies according to income, exposure and level of preparedness (Coulter et al. 2016). In a manual for estimating the socio-economic effects of natural disasters, Economic Commission for Latin America and the Caribbean (ECLAC) provides broad outlines for the most probable types of infrastructure that may be damaged by a disaster. For example, the manual explains how floods can contaminate clean water supply, damage buried pipes and semi-buried tanks, and pump equipment (de Leon 2007). Fragility of natural environment also exacerbated vulnerability.

17.3.2 Ecological Vulnerability

Recently, several studies have been done to identify vulnerability to hazards in socio-ecological system (Berrouet et al. 2018; Pattison-Williams et al. 2018). It is recognized that social as well as natural systems are inherently coupled. Hence, both are considered in a more holistic approach to measure vulnerability (Adger 2006). However, the ecological vulnerability is generally regarded as the inverse of resilience (Hagenlocher et al. 2018; Timmerman 1981). A resilient ecosystem is not that where people remain unchanging or changes are prevented rather various changes are occurred in that ways where the structure of ecosystem is not altering fundamentally (Aroca-Jiménez et al. 2018; Chen et al. 2019). But, accurately which elements of the ecological system are able to resilient not clearly understood yet. Moreover, a particular challenging task is to incorporate the variables and indicators those can measure the ecological vulnerability. In comparison of social vulnerability, the ecological vulnerability is less explored, analyzed and understood subject matter (Etkin 2016; Fakhruddin et al. 2019). Therefore, low depth studies have been conducted recently on ecological vulnerability. Moreover, the ecological vulnerability is usually confined in some measurements of exposure and/or state of the geophysical aspects which is maybe inadequate measures of the ecological vulnerability (Fatemi et al. 2017; Johansson and Hassel 2010).

However, though several recent advance efforts have been done to develop the theoretical/conceptual models and frameworks for measuring ecological vulnerability. But there is no commonly agreed definition or framework exist that can provide an explicit guide for developing indicators to measure ecological vulnerability quantitatively (Gautam and Dong 2018; Tapsell et al. 2010; Timmerman 1981; Zakour and Swager 2018). Future studies should therefore need to conduct for clear ecological vulnerability conception particularly for the ecological systems.

Table 17.2 Geographical structures and disasters/issues

Geographical type	Different pertinent issues
Small island	Sea-level rise, isolation, and salt water encroachment
Developing city	Insufficient infrastructure, social omission, squatter and slum communities
Mountainous area	Glacier melting, landslides, deforestation, soil erosion
Semi-arid area	Elevated precipitation variability, desertification
Low-lying coastal area	Salt water encroachment, slow river flow, and sea-level rise

17.3.3 Climate Vulnerability

Climate vulnerability mainly deals with various vulnerabilities related to the climate change but some studies considered the climate vulnerability as fatality, social vulnerability of climate change and surprisingly different countries have configured the climate vulnerability by applying different indicators. However, climate vulnerability typically refers the state of climate change (Balica et al. 2012; Emrich and Cutter 2011; Nagy et al. 2019). It depends on the climatic features, such as temperature, rainfall, and various meteorological aspects. Therefore, to practically measure the climate vulnerability, types of geography needs to be identified. Some of the potential geographical structures and disasters/issues are given in Table 17.2.

17.3.4 Social Vulnerability

Social vulnerability is mostly visible after a hazard event (Cutter et al. 2003; Spurlock 2018; Tapsell et al. 2010). The nature of social vulnerability depends on the nature of hazard. Certain properties of a social system make it more vulnerable to certain types of hazards than to others (Ahamed 2013; Dintwa et al. 2019). Therefore, it can be said that social vulnerability is not a function of hazard rather it is function of social systems. There is no unique definition of social vulnerability. Therefore, different authors have used it differently. Current literature reveals the fact that social vulnerability can encompass various aspects and features, which are linked to socially created vulnerabilities (Cutter et al. 2003; Mavhura et al. 2017). Simpson and Katirai (2006) have developed a definition of social vulnerability. They define six attributes to characterize social vulnerability.

- the differential exposure to stresses experienced or anticipated by the different units exposed;
- a dynamic process
- rooted in the actions and multiple attributes of human actors
- often determined by social networks in social, economic, political and environmental interactions
- manifested simultaneously on more than one scale
- influenced and driven by multiple stresses.

Different matters have contribution to create social vulnerability. From existing literature, it is apparent that social vulnerability consists of various social matters. Social vulnerability is much more broadly used for estimating any kinds of disaster vulnerability (gender, age and income distribution). Within the debate of social vulnerability, the term exposure also deals with social vulnerability because that increases defenselessness such as exclusion from social networks (Birkmann 2006).

The characteristics of external relations and the internal value system contribute to determine its level of vulnerability. For example, a functioning cultural community may provide strong social networks. Level of education and income among men and women vary significantly. Age structure is also important indicator to determine social vulnerability (Schneiderbauer and Ehrlich 2006). People, who are socially deprived, disabled or in poor health are more vulnerable to flooding than others. Population subgroups that are vulnerable to the effects of flooding including the elder people, women, children, minorities, individuals with disabilities and those with low incomes (Queste et al. 2006). Factors such as language, community isolation and the cultural insensitivity of the majority population may also affect the social vulnerability. Within this approach, the following variables reflect social vulnerability: age, gender, employment, car ownership, disability, language skills (de Moor et al. 2018). Similarly, for capturing social vulnerability Baum et al. (2008) have used age, proportion of male and female, social capital or social networks, social isolation and account of race and ethnicity. Birkmann (2006) have used social networks and membership of organizations as the variables of social vulnerability. They also used gender distribution as the variable of social vulnerability.

Common variables include socio-economic status, presence of disabilities, age, household or family structure, racial background, ethnicity, the social capital and social networks associated with adaptive capacity. A number of these potential variables are very familiar having for more than 50 years, repeatedly proven their statistical power in urban social analysis (Chen et al. 2013; Cutter et al. 2003; Emrich and Cutter 2011). People having poor education and insufficient knowledge are less able to respond appropriately in changing environment. In addition, fatalism beliefs that the creator leads the natural hazards so it is unpredictable, which made them vulnerable to disasters (Schneiderbauer and Ehrlich 2006). On the contrary, Adger (2006) mentioned that less educated unskilled people are more vulnerable to hazards than communities are exposed. Children or elderly people at risk in shelter of refugee camp situations. More number of household members can create a household more vulnerable because large family cannot move swiftly in disastrous situation. On the other hand, small size of family can easily move to safe place in disastrous situation with their family members. Local social organizations may be the most important variable of social vulnerability/capacity/resilience because such organizations provides information and resources (Okayo et al. 2015). Disabled people and who did not face hazards in previous, less awareness and preparedness, lacking of shelters/hospitals, unemployment, fragile quality of infrastructure may also be the causes of vulnerability (Smith and Frankenberger 2018; Tapsell et al. 2010). Inadequate flood defenses and preparedness, lack of awareness about the flood hazard make people vulnerable to flood disaster (Azad et al. 2013). Having access to information can be one way of decreasing vulnerability and ability to recover can be determined by the existence of social or neighborhood networks (Schneiderbauer and Ehrlich 2006; Sebald 2010). Weak early warning systems, lack of communications infrastructure and critical facilities further magnify vulnerabilities of communities for future disaster situations. The population's access to information is important for knowledge related with early warning of post-disaster emergency and relief actions. In addition, cost for medicine, medical attention and funeral ceremonies might be added. For most developing countries like Bangladesh, these kinds of variables can be used.

17.3.5 Economic Vulnerability

Vulnerability in many ways is related to poverty. The poor societies have little resources and opportunities to reduce vulnerability significantly. However, poverty has a general link with income, occupation, availability of wealth. An economic factor is considered as a highly influential factor to create vulnerability at the national scale. A financial resource and a strong economy have contribution to reduce vulnerability (Ahsan and Warner 2014; Ujjwal et al. 2019). The Fig. 17.4 shows the process of economic vulnerability.

Economic vulnerability is a set or composite index of indicators such as degree of export dependence, lack of diversification, export concentration, share of modern services and products in GDP etc. (Mechler et al. 2006). Income, employment, health insurance, house insurance, flood insurance and savings are the variables that have great role to create or reduce vulnerability to any kinds

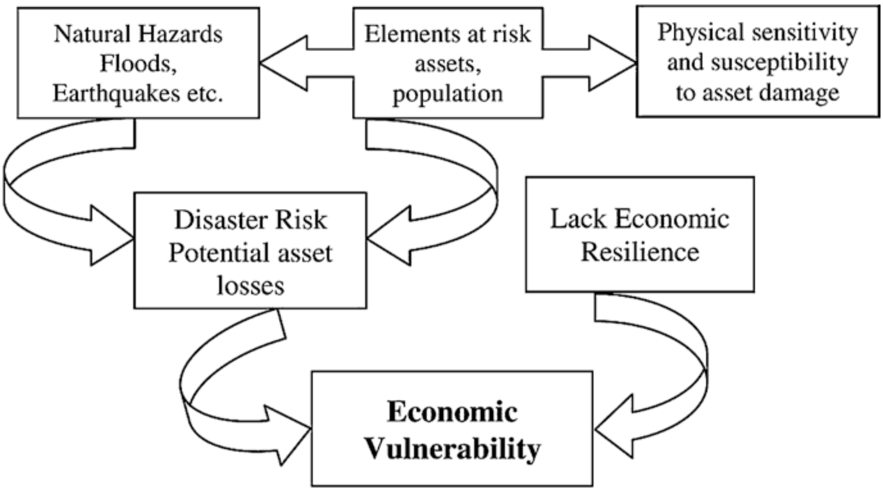

Fig. 17.4 Economic vulnerability system due to natural hazard (modified from Mechler et al. (2006))

of hazards or disasters (Fakhruddin et al. 2019; Mavhura et al. 2017). Insurance can help to manage disaster risk and reduce losses. Rich people have ability to absorb losses as they can recover the loss of materials and goods due to hazards quickly. High-income families have high savings so they can recover any financial loss easily (Olorunfemi 2011). The ability to recover can be determined by household savings and individual or family related insurances. Birkmann (2006) have used income, loans, savings and employment as the economic variable of vulnerability. They have also used land ownership as the variable of vulnerability.

17.3.6 Structural Vulnerability

Structural vulnerability is another influential factor in flood disaster. It can increase the intensity of flood hazard. Previous literatures have shown very few variables to determine structural vulnerability. Among those housing quality, road networks, existence of evacuation road, drainage system, and flood dams are mostly apparent (Coppola 2006). Structural vulnerability can classify into three broad categories like, transport systems (roads, railways, bridges etc.), utilities (water, sewerage, and electricity) and telecommunication (Masuya et al. 2015). It also involves those factors, which are constituted by physical environment. The quality and altitude of houses/buildings are important in structural vulnerability. For instance, a building may be located in a flood prone zone but raising the structure of that building may reduce its structural vulnerability. Generally, the stability of a house depends on the material used to build it and it relates to determining vulnerability emanated from cyclones, floods, etc. Buildings at low elevation near the coast or in occasionally flooded areas might be vulnerable to floods (Cogswell et al. 2018). Houses in the hazard-prone areas are a part of exposure that characterizes the spatial dimension of vulnerability. The location of human settlements and infrastructure plays a crucial role for determining the susceptibility of a community. Living in dangerous locations makes individuals or communities defenseless against hazards (Chen et al. 2016). Schneiderbauer and Ehrlich (2006) stated that, the poor people tend to live in locations of higher risk, such as polluted areas, which makes them structurally vulnerable. In potentially hazard-strike areas of communication systems can be measure by the network of roads or other traffic lines and mobile phone coverage (Rashid 2013).

17.3.7 Institutional Vulnerability

The institutional infrastructure provides the framework of management to mitigate disasters, increase preparedness, and response activities. Assessment of the efficiency of an institutional setting can often only be approached by using indirect variables, such as medical infrastructure. Existence of emergency management committee and aid during disastrous situation works as a remedy of reducing vulnerability (Adger 2006). Institutions addressing floods or flood-related disasters. It may influence the vulnerabilities of households and communities through several pathways. Lack of early warning systems, emergency service, governance and institutions can amplify the vulnerability at household or community level (Mavhura et al. 2017). Weak early warning systems, lack of communications infrastructure and critical facilities further magnify vulnerabilities of communities for future disaster situations (Dewan et al. 2007). The people's access to information is an important knowledge related with early warning as well as post-disaster emergency along with relief actions. Influences of institutionalized capacities and practices on the disaster cycle are mediated by ecological and social resilience as well as attributes of the flood event itself.

17.3.8 Demographic Vulnerability

Very few literatures utter the name of demographic vulnerability. Population structure such as a high dependency ratio, number of young and elderly people among total population indicate demographic vulnerability (Birkmann 2006). Researchers should assess the linkages among the concept of people about hazards, locational, structural and demographic vulnerability. Population's vulnerability to all types of disasters depends on demographic growth, the pace of urbanization, settlement in unsafe areas, environmental degradation, climate change, and unplanned development. However, demographic factor has much more contribution to create vulnerability. Population density, population growth rate also may be added as demographic vulnerability indicator (Adger 2006; Cutter et al. 2003).

However, vulnerability factors mentioned before are interconnected with each other (Fig. 17.5). Economic vulnerability can lead to the social vulnerability. Alternatively, the consequence of social vulnerability makes demographic and institutional vulnerability. It is also partially responsible in creating physical and environmental vulnerability.

17.4 A Debate on Vulnerability Equations

Several institutions and experts for assessing, measuring and evaluating vulnerability of various hazards and disasters have developed a significant number of vulnerability equations. In this study, the equations related to flood vulnerability have been considered.

Literature supports that in formulating vulnerability the first initiatives was taken by UNDP in 2004 (UNDP 2004). UNDP provided formula is given below:

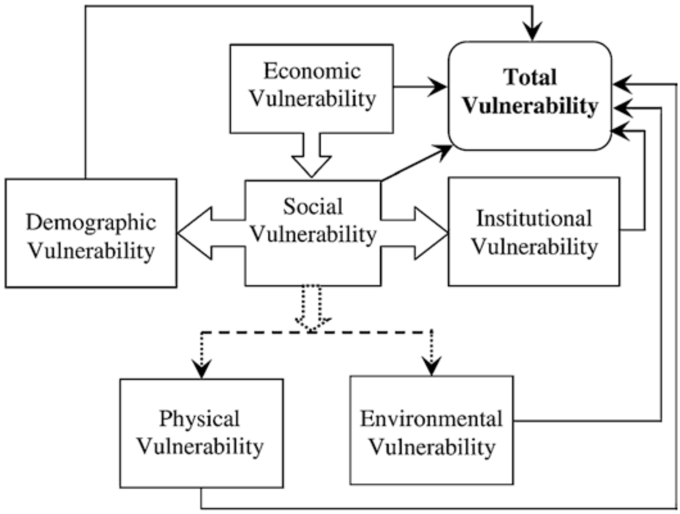

Fig. 17.5 Interconnection of vulnerability factors

$$Vulnerability = \frac{Hazard \times Risk}{Manageability \,/\, coping\, strategies} \tag{17.3}$$

The extent of a disaster cannot be measured without knowledge of the resilience of the affected groups (Alwang et al. 2001). Thus, they stated vulnerability equation as follows:

$$Vulnerability = Hazard - Coping \tag{17.4}$$

Simpson and Katirai (2006) used a vulnerability equation for measuring vulnerability of a community. That is:

$$Vx = \sum\left[\left(Hapafa\right) + \left(Hbpbfb\right) + \ldots\right] \times \sum\left[\left(w1VM1 + w2VM2 + \ldots wnVMn\right)\right] \tag{17.5}$$

where: V = Community Vulnerability; x = location of community; Ha,b,c…. = Hazard agent (flood, earthquake, hurricane….); f = frequency of hazard; p = probability of hazard; w = weight; VM = Vulnerability measure/indicator and n = number of measures.

Simpson and Katirai (2006) have developed another equation for measuring vulnerability as:

$$\begin{aligned} Vulnerability = {} & hazard \times probability \times frequency \\ & \times Vulnerability \quad measures \quad \left(VM\right) \end{aligned} \tag{17.6}$$

Flood vulnerability is a combination of various factors and/or variables. Shoeb (2002) expressed vulnerability equation as:

$$Vulnerability = f \begin{bmatrix} physical \quad characteristics + human \quad characteristics \\ + flood \quad characteristics \end{bmatrix} \tag{17.7}$$

Finally, Shoeb (2002) introduced the household vulnerability equation as follows:

$$\begin{aligned} Household \quad vulnerability = f\left[AHSICFPGET\right], \left[Sc,Sb,Tt,St,Ro\right], \\ \left[D,Dt,Sd,Ss,W,V,Po,R\right], \left[Wo,Wt,Wa\right], \ \left[Tr,Ra,Rq\right] \end{aligned} \tag{17.8}$$

where, A = Age profile, H = Health status, S = Savings of households, I = Income of households, C = Cohesiveness of local community, F = Flood knowledge, P = Population density, G = Gender, E = Ethnic class, T = Transport network, Sc = Susceptibility of building contents to damage, Sb = Susceptibility of building fabric, Tt = Time taken to restore infrastructure, St = Number of stories, Ro = Robustness of building fabric, D = Dept of flood, Dt = Duration of flood, Sd = Sediment concentrations, St = Sediment size, W = Wave/wind action, V = Velocity, Po = Pollution load of flood waters, R = Rate of water rise during flooding onset, Wo = Warning given of not, Wt = Warning time provided, Wa = Advice content of warning, Tr = Time taken for assistance to arrive after of during event, Ra = Amount of response, and Rq = Response quality.

All societies are vulnerable to floods, under different cases and situations. Balica et al. (2012) has introduced the following vulnerability equation:

$$Vulnerability = Exposure + Susceptibility - Resilience \tag{17.9}$$

For measuring social vulnerability specifically some vulnerability equations have been developed by disaster experts. For instance, Simpson and Katirai (2006) have developed a formula for measuring social vulnerability as follows:

$$\begin{aligned} & SoVI = Personal \quad wealth + Age + Density \quad of \quad the \quad Built \quad Environment \\ & + Single \quad Sector \quad economic + Housing \quad Stock \quad and \quad tenancy \\ & + Race \ \left(African \quad American + Hispanic + Native \quad American + Asian\right) \\ & + Occupation + Infrastructure \quad Dependence. \end{aligned} \tag{17.10}$$

Evaluating the previous vulnerability equations, the following formula has been devised by them.

$$FVI = f\left(Soc\ Vul, Eco\ Vul, Phy\ Vul, Ins\ Vul, Env\ Vul\ Dem\ Vul,\right) \tag{17.11}$$

where, FVI = Flood Vulnerability Index, Soc Vul = Social Vulnerability; Eco Vul = Economic Vulnerability; Phy Vul = Physical Vulnerability; Ins Vul = Institutional Vulnerability; Env Vul = Environmental Vulnerability and Dem Vul = Demographic Vulnerability

17.5 Qualitative to Quantitative Vulnerability

A number of vulnerability theories, frameworks/models and measuring methods have been developed by various scholars to systematize vulnerability. Conceptual framework or models are very essential for developing methods of measuring vulnerability and the systematic identification of relevant indicators (Birkmann 2006). Focusing on few models and frameworks, the present study presents a vulnerability framework.

17.5.1 The Pressure and Release Model (PAR Model)

The pressure and release (PAR) framework was introduced by Blaikie et al. (2005) in early 1980s on the basis of social characteristics of vulnerability. The PAR framework reveals that generally disaster occurs owing to two elements including, vulnerability progression as well as frequency of hazard (Wisner 2006). The PAR approach underlines how disasters occur and when natural hazards affect vulnerable people (Wisner 2010). The release idea is incorporated to conceptualize the reduction of disaster to release the pressure, to reduce vulnerability. The PAR is related to human vulnerability and exposure to physical hazard. It also gives a clear concept about, how vulnerability is initially generated by economic, social, environmental, institutional, demographic and political processes and then happens a disaster (Fig. 17.6). This framework identifies disasters as the meeting point in between socio-economic influence and physical exposure. It focuses on those circumstances which create exposure hazardous and cause of vulnerability. Blaikie et al. (2005) noted that according to PAR framework the physical evolution of vulnerability is threefold: ① root causes, ② dynamic pressures and, ③ unsafe conditions. It highlights those environments which make exposure unsafe and lead to vulnerability. This framework emphasizes on the differences in vulnerability with various exposure elements (i.e., class, ethnicity).

However, even it highlights vulnerability clearly, but the PAR framework apparently less comprehensive in wide concerns in sustainability science (Dintwa et al. 2019). The PAR framework argues that the disasters do not occur naturally, but relatively the product of the social as well as political forces. In this framework

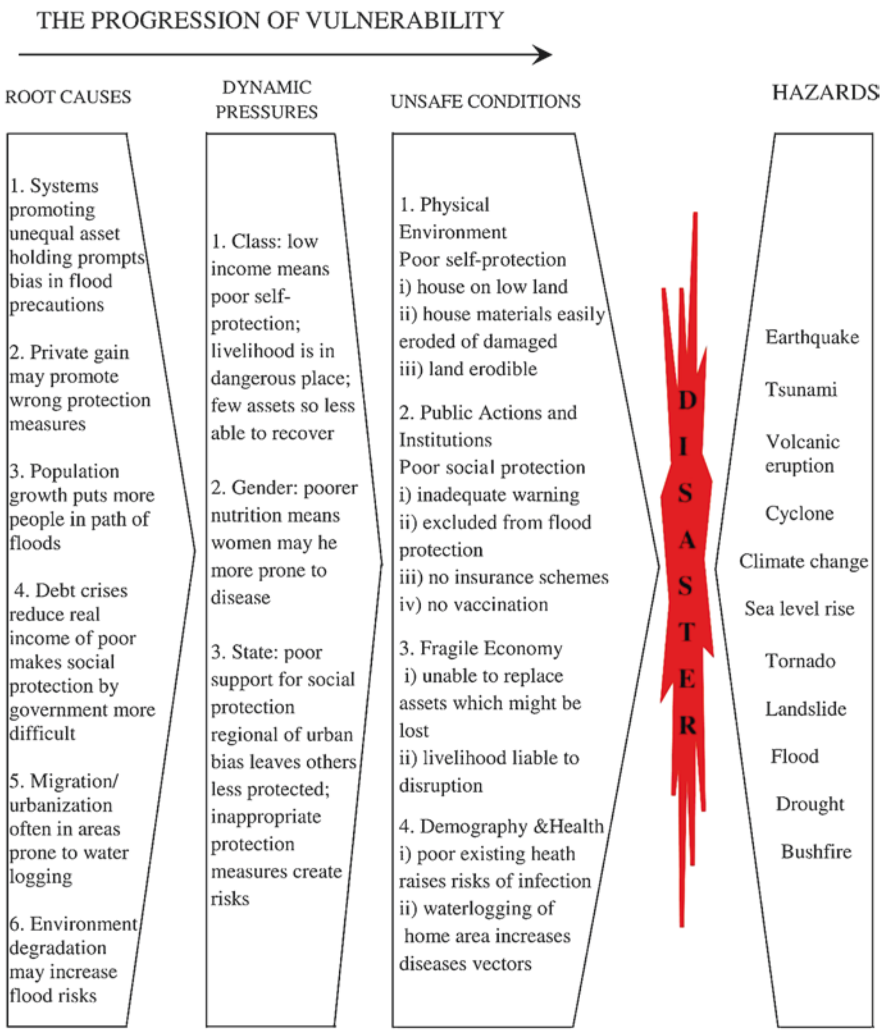

Fig. 17.6 The Pressure and Release Model (PAR model) (tailored from Blaikie et al. (2005))

obvious attention has been given to the root causes and has drawn on the typical baseline of risk and in intersection of the hazard as well as vulnerability. These notions lead to measure vulnerability qualitatively (Ahmed and Kelman 2018). Moreover, it did not address human-environment interaction to consider biophysical vulnerability. The PAR framework gives a little explanation of the hazard's underlying sequence structure (Turner et al. 2003). According to Cutter et al. (2003) this framework did not report completely regarding the characteristics of sources of risk and interaction of social and physical environment in hazard creation. Therefore, it is typically applicable in qualitative analysis. Dunno (2011) claimed that the PAR framework does not bear the response loop for the policy along with mitigation interferences. However, it has an argument for combination of policy exercise affecting vulnerability to environmental hazards but it does not show any ability to integrate the mitigation policies, and no hints to consider multiple hazards study (Dintwa et al. 2019).

17.5.2 Turner et al.'s Vulnerability Framework

Turner et al. (2003) also have introduced a vulnerability framework which defines vulnerability in a broader sense (Fig. 17.7). Their vulnerability framework encompasses exposure, sensitivity and resilience. It also explains the responsible factors and linkages that affect the vulnerability of human and environmental system in a space. They have claimed that this vulnerability framework is a comprehensive framework (Turner et al. 2003). It analyzed vulnerability consistently and offered a comprehensive classes of the factors as well as the linkages those include a combined system's vulnerability to natural hazards (Balica and Wright 2010). It was guided from necessity to propose an appropriate template of reduced-form to analyze the substantial systemic characteristics of a problem. This is a descriptive framework to assess vulnerability qualitatively. It mainly deals with the inclusive linkages between human and biophysical (environmental) circumstances and processes. Moreover, it includes the man-environment system where vulnerability is present, including exposure as well as responses (Turner et al. 2003). The framework underlines that the place-based vulnerability investigation requires to consider at multiple scales (e.g., local, regional, and global scales). In addition, it is needed to examine the coupled man-environment system comprehensively rather than that reductionist manner (Füssel 2007).

Vulnerability Framework Components of vulnerability identified and linked to factors beyond the system of study and operating at various scales. The complete framework has been explained in Fig. 17.7 with the spatial scales, connecting place (blue), to region (yellow) and to globe (green).

The different parts of vulnerability have been clarified in Fig. 17.8. The hazards of a system are arisen from external and internal of the system and place but, their exact characteristics are usually specified to the place-based system (Turner et al. 2003). For these causes, the hazard itself is located both inside as well as outside the place of system. Thus, the hazard holds potentiality to affect joined system negatively, with that manner where a system experiences the perturbation and stress. These circumstances comprise of both the social and the biophysical capital those influence the standing coping techniques. In human subsystem, these mechanisms might be individual and/or independent action or policy-based changes. The social and biophysical surviving mechanisms influence each other. As a result, response of human subsystem might help the biophysical subsystem relatively to cope, or vise-versa (Füssel 2007). The responses (planned, communal or private, personal or institutional, short or long-term) collectively define the resilience of a system (Balica and Wright 2010).

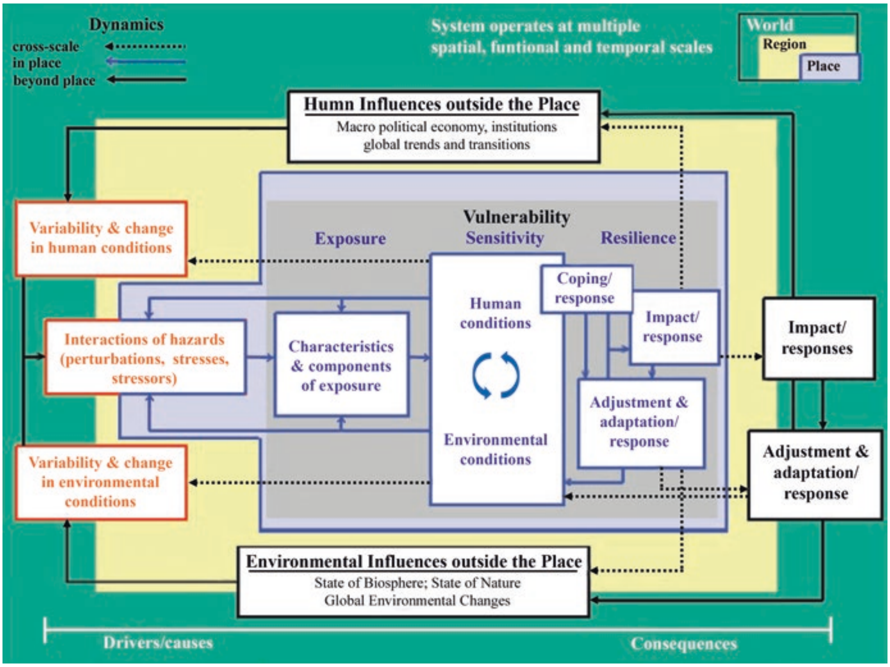

Fig. 17.7 Typical vulnerability concepts in different periods (Turner et al. 2003)

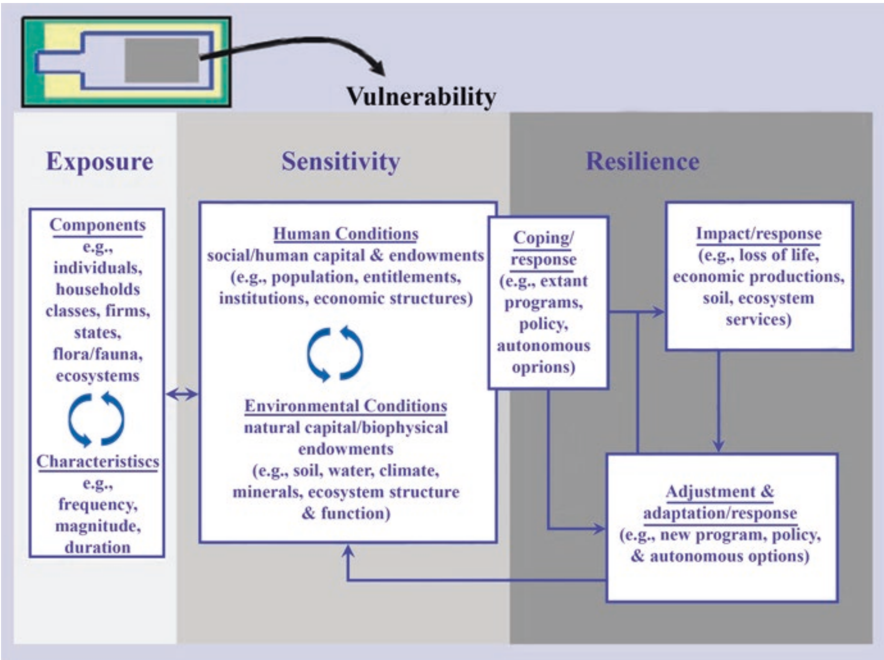

Fig. 17.8 Features of exposure, sensitivity, and resilience components of vulnerability framework (Turner et al. 2003)

It shows the complications and interactions related to vulnerability analysis in human-environment system. The systemic qualities of this framework are exposed left to right (hazards and impacts) or right to left (impacts and hazards). The utilization of this framework depends on the requirements of a user. However, it contains significant determinants to identity the resilience of a human-environment systems, such as it reflects the notion of coping capability (Balica and Wright 2010).

17.5.3 BBC Conceptual Framework

One more framework for measuring vulnerability was developed by Bogardi et al. (2004). This framework is called "The BBC-framework". The BBC conceptual framework combines different elements of the frameworks discussed earlier. It underlines the need to view vulnerability within a process (dynamic), which means focusing simultaneously on vulnerabilities, coping capacities and potential intervention tools to reduce vulnerabilities. This framework emphasizes the necessity to focus on social, environmental and economic dimensions of vulnerability. It declares that vulnerability should be measured with respect to economic, social and environmental dimensions. In this framework, risk is defined as an interface of hazard and vulnerability of a system that is exposed to the socks. Vulnerability has been considered as the formation and an interaction of the social, physical, economic, environmental, demographic, and political exposure. Moreover, susceptible elements and coping capability to these elements are explained in this framework (Fig. 17.9).

The BBC-framework typically configures two probable ways to reduce disaster risk as well as vulnerability: ① preventive measures for instance, planning and consciousness rising before occurring a disaster (t: 0); ② disaster management for example, evacuation and urgent response in disastrous situation (t: 1) (Birkmann 2006). The interference system such as current crisis management scheme has direct consequences to outline the total vulnerability and determine the degree of risk. The key benefit of it is that, the framework clearly indicates the response loop system to reduce the risk. It suggests that measurement of total risk and vulnerability would consider the existing disaster management plan simultaneously, the existing disaster management plan should confirm vulnerability reduction. Moreover, it focuses that to measure vulnerability exposure, susceptible elements as well as coping capacities must need to consider.

17.5.4 Proposed Vulnerability Framework

This study conceptualized the quantitative vulnerability framework to quantify vulnerability to environmental hazards. The study emphases to the quantitative vulnerability components of the environmental hazards. The framework considers all the dimensions and factors of vulnerability to measure vulnerability quantitatively in a

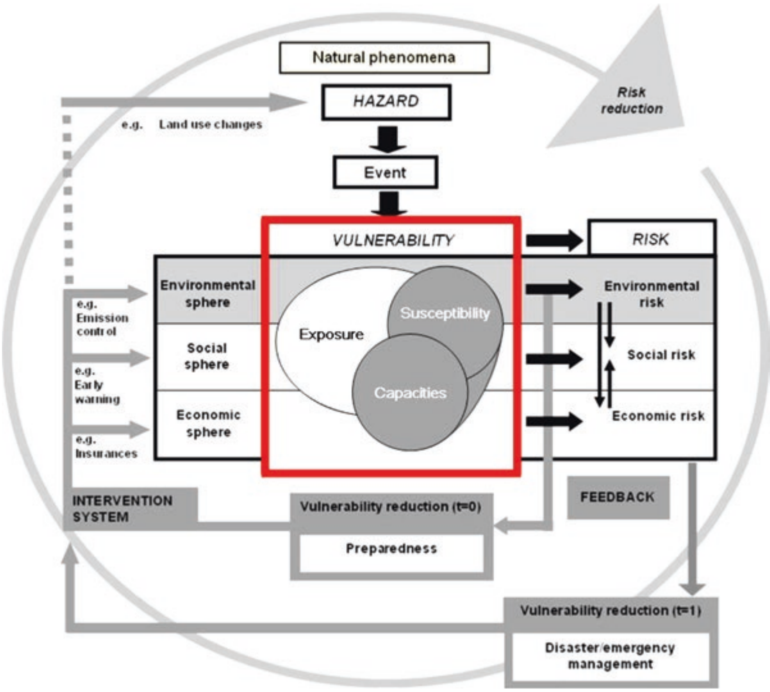

Fig. 17.9 BBC Framework (Bogardi et al. 2004)

place. The conceptual framework (Fig. 17.10) presents a systematic approach considering various vulnerability factors and variables as a subject of analysis. It views vulnerability as blend of various factors like demographic, social, economic, structural, institutional and environmental influences. Vulnerability is a dynamic feature that changes over time and space. Several techniques were used to develop vulnerability framework (Ahsan and Warner 2014; Berrouet et al. 2018; de Leon 2007; Sebald 2010).

This study endeavors to integrate the best method in the course of developing vulnerability framework. This framework deals with the dimensions of vulnerability, variables of vulnerability dimension, and indicators of the respective variables. According to this framework first of all need to identify the factors (dimensions) vulnerability to environmental hazards. Variables of a given factor (dimension) should be identified. After that, the indicators of a specific variable also need to define. To assign weight values to the specified variables and indicators, Analytic Hierarchy Process (AHP) is used (Saaty 1990) in this framework to get numeric number of the variables and indicators. Scientific explanation of AHP is given in next paragraph. However, the quantitative score of a specific factor (dimension) can be obtained by the following equation:

$$Vulnerability \quad Score = \sum Variable \quad Weight \times Indicator \quad Weight. \tag{17.12}$$

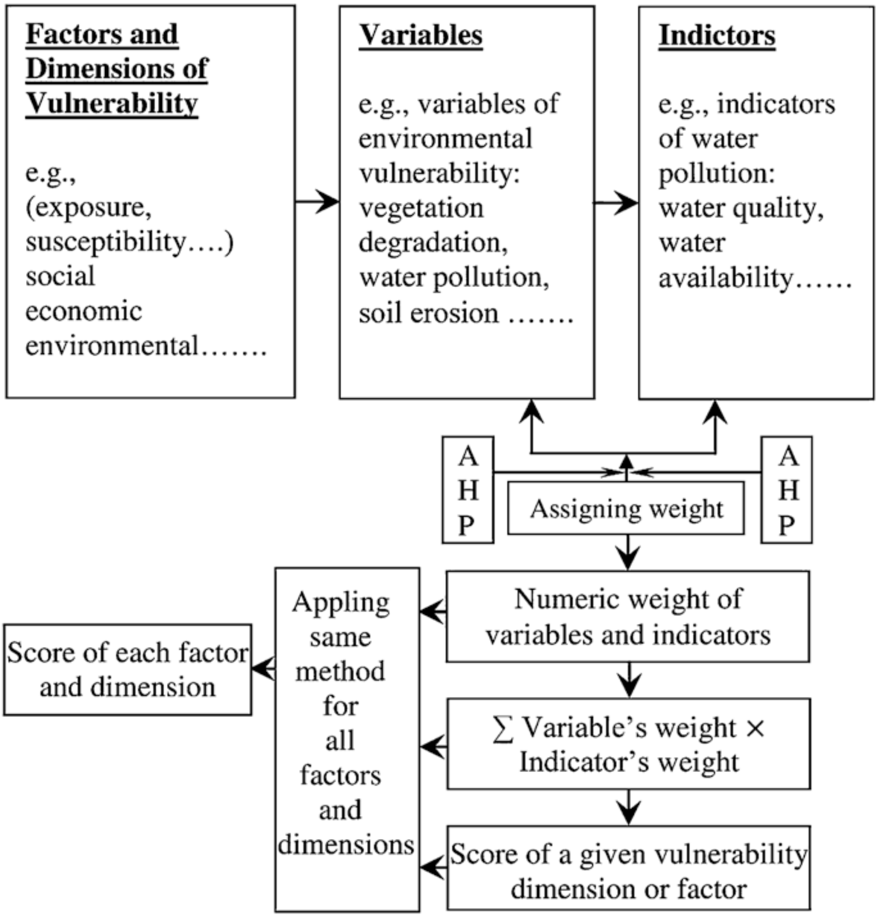

Fig. 17.10 Model of quantifying household vulnerability and vulnerability indexing

Finally, with this procedure the quantitative/numeric scores of all dimensions of vulnerability to environmental hazards can be calculated.

The AHP is a structured technique to deal with complex decisions. Rather than prescribing a "correct" decision. The AHP originally has been developed by Saaty (1990) and mostly referred as the Saaty method (Coyle 2004; Rahman and Saha 2007). The AHP helps the decision makers to find the one that best suits for needs and understanding of the problem. The AHP has developed based on mathematics and psychology. It has three basic principles like decomposition, comparative judgment and synthesis of priorities. This process provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. The AHP is based on pairwise comparisons with respect to the element at the next upper hierarchical level (i.e. among variables and indicators). Ratings of the elements can be arranged as numerical numbers with the comparison matrix developed by Saaty (1990). Based on this, relative weights for all elements can be calculated with the eigenvalue method, indicating the priority level for each element in the hierarchy.

17.6 Conclusions

This quantitative approach could be applied to appraise the effectiveness and/or impact(s) of a hazard or guidelines by reproducing the values of contributing dimensions of vulnerability and its variables and indicators. The application of this quantitative framework creates a platform to assess location-specific vulnerability of environmental hazards. Moreover, with this method a sensitive analysis can be done by potential vulnerability dimensions of environmental hazards within different values (e.g., social, economic, institutional, structural, environmental, demographic, geographical, political, cultural, ideological etc.). Even considering the dimensions of vulnerability over time, a spatial variation of vulnerability also could be measured with this framework. However, to exploit this framework, policy makers could also choose their most favorable approaches in policy formulation to reduce disaster risk. The methodology of selecting responsible dimensions of vulnerability, variables and indicators in conjunction with weighing procedure might modify to measure vulnerability quantitatively for a specific community or region. This process of quantitative vulnerability measuring is simple but very efficient tool to find, and evaluate the vulnerability scenario of a hazard-prone area.

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Chapter 18
Soil Microarthropods and Nutrient Cycling

Gopakumar Lakshmi, Bernard N. Okafor, and Donato Visconti

Abstract Soil microarthropods are soil macrofauna which help in assisting soil quality, increasing soil carbon and has a major role in soil biogeochemical cycles. Even though the importance of soil microarthropod groups is studied, their role in soil biogeochemical cycles and soil food webs is not well understood compared to other organisms. In this chapter we explain the importance of soil microarthropods as important components of soil biogeochemical cycles. The role of soil microarthropods in soil soil food webs and biogeochemical cycles is also explained. Moreover, the relationship between soil microarthropods, nutrient cycles and ecosystem management is examined to elucidate the importance of these organisms in soil ecosystems. As climate change is a major issue which has relation to soil biogeochemical cycles, the connection between soil microarthropods, biogeochemical cycles and climate change is discussed. Finally, research gaps are identified in soil biogeochemical cycle related microarthropod research, and important research areas related to this field are proposed. We believe that this chapter will be significant as a good reference related to soil microarthropods, biogeochemical cycles and climate change nexus.

Keywords Acari · Collembola · Climate change · Soil biogeochemical cycles · Soil organic carbon · Soil quality

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_18

18.1 Introduction

The soil ecosystem accounts for high diversity of flora and fauna and has relationship with other ecosystems like hydrosphere and atmosphere. It also has relationship with biosphere and it holds high diversity of floral and faunal components. The soil fauna also supports soil ecosystem by providing a number of ecosystem functions. All these subjects are addressed in this chapter on soil microarthropods and nutrient cycling.

18.1.1 The Soil Ecosystem

Soil as an ecosystem is a dynamic system which supports life on earth by providing food and has a major role in climate regulation through provision of ecosystem services like nutrient cycles. In addition to providing a substrate on which many plants and animals can survive, soil ecosystem help in providing food, and thus play a major role in sustaining life on earth. Soils also form an important part of water cycle, as soil water is a major form of water source to plants and microorganisms. The favourable conditions in soils like soil water and soil air create a 'microhabitat' supporting various flora and fauna. Fertile soil is an inseparable part of food security as it is a mandate for healthy and quality food to animals and human beings. In general, major ecological functions of soil ecosystem has been recorded (Larson and Pierce 1991) namely promoting plant growth, reception, holding and release of water, recycling carbohydrates and nutrients through mineralisation, transferring of energy in the detritus food chain and its role as an environmental buffer.

18.1.2 Soil Formation

Soil formation occurs as a result of series of events like weathering, mineralisation etc. Pedogenesis is a slow process which takes a number of years. This involves the conversion of parent material to mature soil through various process like weathering and mineralisation (Jenny 1994). Factors of soil formation include parent materials, climate, vegetation, time, slope and biological activities of soil fauna. As soils are sources of plant nutrients which help in sustenance of life on earth, the role of good quality soils in supplying the basic needs of man cannot be underestimated. One of the global problems faced by the world is food insecurity which stems from the low quality of soils which can be due to poor nutrient cycling and recycling. Hence maintenance of soil quality being major part of this task is performed by various organisms which contribute to a critical part of global food security.

18.1.3 Soil Fauna

The soil organisms ranging from bacteria to higher vertebrates has a major role in regulating the ecosystem balance through their role in various food chains and food webs.

The soil fauna is generally divided into three according to their size

1. Microfauna with a body size between 20 μm and 200 μm including protozoa, small mites, nematodes, rotifers, tardigrades, copepods and crustaceans
2. Mesofauna whose body size is between 200 μm and 2 mm and comprises microarthropods such as mites and springtails (main representatives of this group), nematodes, rotifers, tardigrades, small araneidae, pseudoscorpions, opiliones, enchytraeids, insect larvae, small isopods and myriapods
3. Macrofauna with a body size between 2 mm and 20 mm. Some earthworms, gastropods, isopods, myriapods, some araneidae and the majority of insects are included in this category
4. Megafauna which comprises organisms with size greater than 20 mm like large invertebrates (earthworms, snails, myriapods) and vertebrates (insectivores, small rodents, reptiles and amphibians).

Arthropods constitute about 20% of the soil fauna and through their continuous activities such as burrowing, ingesting of soil particles and the decomposition of soil organic matter, soil nutrient cycling continues to take place and leads to changes in soil physicochemical properties (Culliney 2013). Decaens et al. (2006) stated that soil fauna make up 85% of soil organisms with arthropods constituting 85% of the population. But only about 10% of soil arthropods are identified (Hawksworth and Mound 1991). The common arthropods found in the soil are microarthropod groups which include Protura, Diplura and Collembola of the class Insecta, Symphyla and Pauropoda of the class Myriapoda, Tardigrada, Copeoda and Isopoda of the class Arachnida (Bagyaraj et al. 2016). Microarthropods have been identified as key players in pedoturbation and pedogenesis. As a significant percentage of total plant litter decomposition is carried out by soil micrcarthropods, they play vital roles in nutrient release and availability. The ecosystem rates of carbon and nitrogen cycling is dependent on the foraging behavior of soil microarthropods. Nutrient availability is affected by the quality and quantity of nutrients released by the activities of soil organisms and the nutrient inputs supplied above soil is related to the soil quality in the various soil layers. Plant responses to soil insect behavior may affect the quantity and quality of organic materials available for decomposition and nutrient release and cycling (Hagvar and Klanderud 2009). In short, nutrient recycling plays a significant role in maintaining soil nutrient balance and soil fertility (Del Toro et al. 2015).

The most important organisms in soil ecosystems include microarthropods due to their importance in biogeochemical cycles. The relative importance of soil microarthropods in biogeochemical cycles has been recognised in a number of studies in the world (Table 18.1).

Table 18.1 Studies on the relationship between soil microarthropods and biogeochemical cycles

Topic	Study area	References
Plant invasion and microarthropod communities	United States	Mc Grath and Binkley (2009)
Microarthropod diversity and biogeochemical cycling	General study	Beare et al. (1995)
Microarthropods and soil carbon sequestration	United States	Soong et al. (2016)
Relation of collembola with carbon and nitrogen cycles	Review	Filser (2002)
Microarthropods and nitrogen cycling	USA Finland USA	Ingham et al. (1986) Sulkava and Huhta (2003) Carrillo et al. (2011)
Relation of microarthropods with carbon and nitrogen cycles	Creation of a model to integrate carbon and nitrogen cycling process	Osler and Sommerkorn (2007)

The various studies on microarthropods explains the major role undertaken by these organisms in carbon and nitrogen cycles and the role in soil carbon sequestration thereby acting as major biological groups to combat climate change. Microarthropods generally helps in increasing the soil organic carbon content by breaking soil litter and adding it to soil carbon pool. In nitrogen cycles, they help to improve soil nitrogen through their excreta. Hence their role is very significant while we discuss the problems related to climate change and methods to reduce the carbon dioxide content in the atmosphere.

18.2 The Soil Food Web

The interrelationships among the various organisms in a soil ecosystem can be represented as the “soil food web” (Fig. 18.1). A soil food web determines how the energy flows from one trophic level to other through the process of eating and being eaten. The presence of soil food webs is due to the relationships based on energy transfer among the different organisms as they decompose organic residues (Cogger and Brown 2016), and hence, can be referred to as ‘detritus food web’.

The detritus food chain is the basis of the hypogean food web and has an essential role within the soil. It is linked to many organisms like isopods, myriapods, earthworms, springtails, mites, larvae and adults of many insects which feed on vegetable and animal detritus deposited on the soil (Menta 2012). In a soil food web, soil bacteria generally promote the degradation of sugars, starch, and proteins, while fungi degrades woody materials. They also release excess of nutrients as soluble ions that can be taken up by plants and absorb nutrients from the residues into their bodies. Nematodes and other mesofauna may release more nutrients into available forms thus feeding bacteria and fungi. Microarthropods may feed fungi and

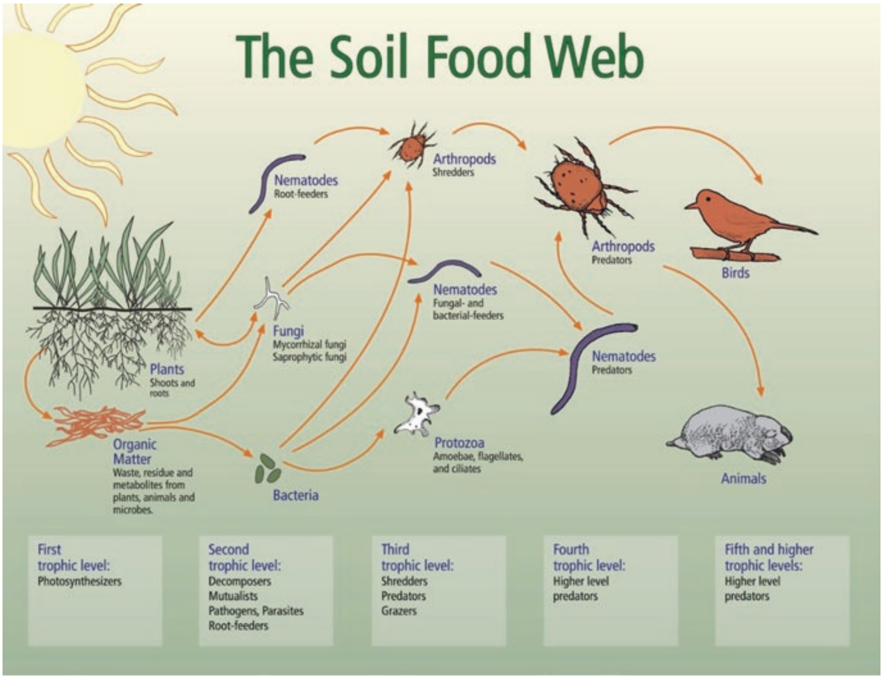

Fig. 18.1 Representation of soil food web (https://www.nrcs.usda.gov)

mesofauna, uptaking nutrients held in their bodies and also increase bacterial and fungal access to litter by cutting and chewing leaf litter and other residues to continue the decomposition.

While considering soil food webs, the various energy pathways in soils has to be mentioned. There are three major energy pathways in soil which are related to roots, bacteria and fungi (Moore 1988) (Fig. 18.2).

The root pathway includes primary herbivores (pathogenic fungi, bacteria, nematodes, protozoa and their consumers), which alters uptake of water and nutrients and reduce primary productivity, which in turn creates abnormalities in root morphology/physiology. The second one namely bacterial pathway includes saprophytic and pathogenic bacteria and their consumers (protozoa, bacterial-feeding nematodes). The third one, the fungal pathway includes various types of fungi and their consumers (fungal-feeding nematodes, oribatid mites and springtails). These three energy pathways unite at higher levels in the food chain which includes soil microarthropods. Most soil microarthropods have an omnivorous food habit, as they and feed on a variety of food sources including herbivores and carnivores and these are actively involved in feeding of other trophic groups in the food web. The omnivorous soil microarthropods feed on small arthropods and their eggs (proturans, pauropods, enchytraeids), nematodes, and on each other. Omnivory is common in grasslands compared to agricultural lands, due to increased diversity of

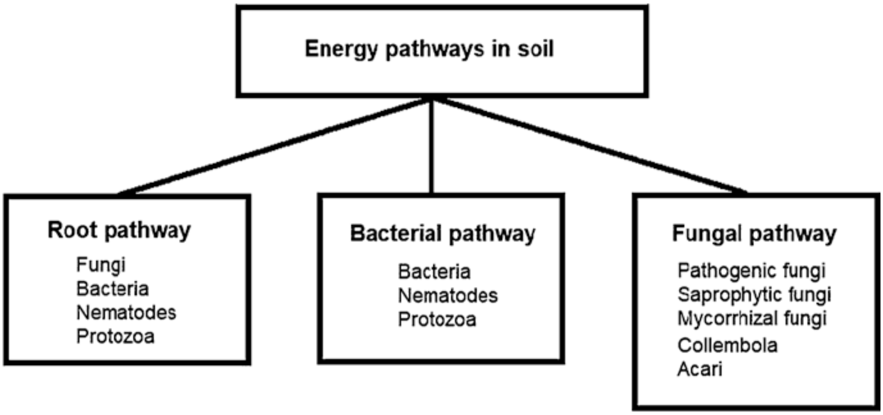

Fig. 18.2 Energy pathways in soil

microarthropods in grasslands. For the same reason, fungal feeding microarthropods are also abundant in forests compared to agricultural lands.

18.2.1 Soil Food Web and Soil Microarthropods

Soil microarthropods ingest and excrete dead plant material thus accelerating plant material decomposition in addition to increasing interfacial contact thus facilitating the colonization by fungi and other microorganisms of plant material (Van Vliet and Hendrix 2007; Siddiky et al. 2012). They may also rearrange fungal spores and bacteria through the soil layers (Palacios-Vargas et al. 2000). Microarthropods like collembola (springtails) are also involved in the mycorrhizal infection of some plants (Endlweber and Scheu 2007; Steinaker and Wilson 2008) and the recycling of organic matter and nutrients in soil (Van Straalen 1998; De la Pena 2009). Among soil microarthropods, springtails (collembola) and mites (acari) play a primary role in organic matter breakdown and its integration to soil (Chavero et al. 2015).

Soil food web structure varies with geography and climate in various ecosystems. In North America, shortgrass prairie (*Bouteloua gracilis*), lodgepole pine (*Pinus contorta ssp. latifolia*), and mountain meadow (*Agropyron smithii*) have similar food web structure (Hunt et al. 1987; Ingham et al. 1989). The relative abundance of organisms within trophic or functional groups may also vary by ecosystem type. It was observed that omnivory is more common in grasslands than agriculture, and fungal-feeders are relatively more abundant in forest than agricultural soils in Poland. In contrast, relative numbers of organisms in each functional group differ in Swedish soils. In the Netherlands, it was observed that disturbances eliminated certain functional groups such as predacious nematodes, omnivorous nematodes, and mycorrhizae present in undisturbed grasslands. It was seen that testate amoebae were reduced in agricultural ecosystems compared to natural ecosystems (Foissner

1997). Also enchytraeidae were less sensitive to seasonal changes in climate than cultivation (van Vliet et al. 1995).

18.3 Nutrient Cycling and Its Importance in Soil Ecosystem Process

Every organism needs to grow, reproduce and maintain its life activities. In addition to these, they need sufficient energy to overcome damage or stress conditions. Nutrients provide energy to organisms for undertaking their daily activities and develop a healthy population, and bring up their next generation through reproduction. Plants provide the basic source of food to higher trophic levels in the food chain like herbivores and carnivores. The growth of plants and their reproduction depends upon the nutrient supply from soils. In order to maintain a balanced nutrient supply, soil biogeochemical cycles operate continuously in the soil ecosystem and hence, they are very important in the survival of flora and fauna on earth directly or indirectly. Nutrient cycling is a complex process which helps to maintain a 'soil carbon pool' which acts as a sink for atmospheric carbon, thereby reducing the impacts of climate change.

18.3.1 Nutrient Cycling in Soils

There are 18 essential elements needed by plants and animals (macronutrients), some which are required in large quantities and the others, required in small quantities (micronutrients). The macronutrients include carbon, nitrogen, oxygen, phosphorus, potassium, calcium, magnesium, sulphur and micronutrients include boron, chlorine, cobalt, copper, iron, manganese, molybdenum, nickel and zinc. In addition to those listed above, some elements such as selenium and iodine, though not required by plants, are essential nutrients for humans and animals.

Nutrients are deposited in soil organic matter in complex organic molecules (proteins, humus and other molecules) that may be broken down in the soil ecosystem, releasing nutrients as soluble ions that can be absorbed by plants. The pace of nutrient release from soils is determined by ecosystem activity and environmental conditions (Cogger and Brown 2016). For this reason, biological activity and nutrient release is slowed/stopped in cold and dry soils, and increases in warm/wet soils.

Nutrient cycling defines the flux of nutrients inside and between living and nonliving components of the soil environment. It involves biological, geological, and chemical processes in the so called biogeochemical cycles (Yan et al. 2015).

18.3.2 Role of Nutrient Cycling in Ecosystems, Survival of Organisms

Soil may be simply defined as the interaction of three components: mineral matter (the bulk of the soil mass, and is made of weathered sediments and rock fragments), organic matter and pore space. Organic matter can vary from 1 to 10% of soil mass, and it improves the physical structure of the soil (enhancing soil porosity and the formation of stable mineral-organic aggregates) and helps in slow release of nutrients. Porosity regulates water and air flows in soil according to pore dimensions. The pores are of two types namely macropores and micropores. Macropores are canals for air and water which regulates water retention and drainage in addition to soil biota dynamics while micropores are the tiniest pores in soil, which holds water so tightly that it do not become available to plants (Ruser et al. 2008). However, this simple definition don't consider the important role of the soil as an ecosystem that converts plants, animals and microbes residues into energy, water, carbon dioxide and plant nutrients, generating humus, the stable organic matter of soil. In this context, soil microorganisms, soil fauna and plant roots play an important role as they are involved in the decomposition of organic matter, formation of humus and the nutrient cycling of many elements (nitrogen, sulphur, carbon). Decomposition of organic matter by soil organisms is crucial for the functioning of an ecosystem because of its substantial role in providing ecosystem services for plant growth and primary productivity (Maharning et al. 2008).

The cycling of nutrients is essential to sustain the life of plants and animals. Generally, each nutrient has its own pathway but many elements appear in more than one cycle. The most important parts of the nutrient cycle relate to the exchange of nutrients among three main pools (Coleman et al. 2018):

1. In the above ground biomass
2. Within the soil organic matter
3. Inorganic form in the soil involving inorganic ions from various sources (weathering of minerals, ions in solution, ions absorbed onto the surfaces of minerals).

The cycling of nutrients between these main pools constitutes a major part of soil nutrient cycles and is one of the major ecosystem functions which sustains life on earth.

18.3.3 Soil Microarthropods and Nutrient Cycles

Soil fauna including microorganisms like bacteria, archaea, fungi, protozoa and viruses play a major role in the biogeochemical cycling of soil nutrients (Tate 2000). Microorganisms are responsible for organic matter decomposition releasing essential inorganic plant nutrients to the soil (Amato and Ladd 1994). They have a major role in the maintenance of nitrate (through nitrification), sulphate (through sulphur oxidation) and phosphate (through phosphorus mineralization) levels in soil in addition to other nutrient cycling processes like oxidation, ammonification and nitrogen fixation. They also have an important role in global carbon cycling by storing carbon and nutrients in their biomass that are mineralized after cell death (Anderson and Domsch 1980). But compared to these organisms, the role of soil microarthropods is very prominent, as they mainly exert a mechanical action on soil organic matter, before it is chemically degraded by fungi and bacteria (both free and intestinal symbionts). In other words, they make organic matter 'more tasty' to microorganisms and speed up the mineralization process. Microarthropods also affect soil porosity and thereby soil aeration by creating macropores in addition to rendering plant residues into forms that are more available to microorganisms.

18.3.4 Biogeochemical Cycles in Soils

Soil biogeochemical cycles are important while considering soil as an 'ecosystem' which supports the survival of a variety of flora and fauna from microbes to vertebrates. The life in soil is possible as a result of a combination of nutrient pathways which help in cycling the various elements through abiotic and biotic components. The major soil biogeochemical cycles involve carbon cycle, nitrogen cycle, phosphorus cycle and sulphur cycle. While carbon and nitrogen cycles are the two major biogeochemical cycles addressed, sulphur and phosphorus cycles are also equally important in balancing soil fertility and survival of various species of organisms.

18.3.5 Microarthropods and Biogeochemical Cycles, Its Relation with Other Process

Microarthropods has an important role in soil biogeochemical cycles, as they act as intermediate agents to release the nutrients locked in litter into bioavailable forms that can be acted upon by soil microbes and can be absorbed by plants. Microarthropods' role in carbon cycle involves the breaking up of soil litter into small pieces which can be acted upon by microorganisms for decomposition. In nitrogen cycle also, soil microarthropods have a good role. The relation between collembola and nitrogen cycle is studied (Faber and Verhoef 1991). Through the establishment of a relationship between nitrogen mineralization rates and collembolan species, based on the habitat use of collembola, it was seen that the concentration of nitrate nitrogen in fresh litter and humus doubled in relation to the vertical stratification of a particular collembolan species (Teuben and Verhoef 1992). During gut passage, collembola has the ability to convert nitrogen during gut passage into faeces with 2.4 times higher nitrate concentration.

18.4 Soil Microarthropods, Nutrient Cycling and Ecosystem Management

The active involvement of soil microarthropods in nutrient cycling is an inevitable part of ecosystem management. The most important functions while considering soil ecosystem management involves mainly decomposition of soil litter, incorporation of soil minerals into biomass of various organisms in the food web, increase in the organic carbon content of the soil etc. The proper co ordinaton of all the aforesaid elements will lead to proper cycling of carbon and nitrogen through various food webs in the soil ecosystem. The first function namely decomposition of soil litter is essential for preventing soil pollution and plant growth. The second function namely incorporation of soil minerals into biomass is required for growth and reproduction of various plants and animals. Microarthropods also increase bioavailability of soil nutrients so that they can be absorbed by the plants and microorganisms and maintain their metabolic activities. The soil ecosystem health generally decreases with intensive management of soil like removal of soil litter, monoculture etc.

18.4.1 The Role of Soil Microarthropods in Ecosystem Management

Soil microarthropods play a prominent role in ecosystem management. Soil microarthropods have a ubiquitous distribution in various ecosystems including forests, grasslands, deserts and agroforestry systems. The proper management of these ecosystems is a mandate for ensuring food security and other ecosystem functions. In tropical ecosystems microarthropods can easily act on soil litter and help in their breakdown, as soil moisture and litter moisture may not be generally a limiting factor. The microarthropod group acari (soil mites) are the major microarthropod group in the forests (Jacot 1940), with suborder Oribatida (oribatid mites) representing highest abundance and diversity (Crossley and Bohnsack 1960; Walter 1985; Schenker 1986). While in temperate ecosystems like pine forests where the soil is rich in nitrogen, microarthropods play an active role in decaying recalcitrant substrates such as pine litter and woody debris (Seastedt 1984), with fungivorous collembola as the dominat group of microarthropods. In these ecosystems, microarthropods affect the abundance, distribution, activity, and diversity of fungal species, and to a certain level compensate the absence of soil macrofauna like earthworms (Crossley 1977; Coleman and Crossley 1996) which help in decomposition of leaf litter. The microarthropods exhibit both a direct and indirect effect on nutrient cycling. The direct effect is by feeding of organic litter/fungi and indirectly by microfloral inoculation, defecation, soil channeling, soil mixing, selective grazing, and microfloral stimulation through feeding of senescent hyphae (Johnston and Crossley 2002).

It was also seen that the presence of microarthropods has relationship to soil ecosystem management. Johnston (1996) compared oribatid diversity in intensively managed stands of loblolly pine on the Coastal Plain of South Carolina and found that oribatid species diversity ranged across a variety of soil types and drainage classes and species diversity was significantly higher in older pine stands compared to new pine stands. Microarthropod diversity also had direct relationship with the time span of a single rotation of the crop. Baguette and Gerard (1993) reported a similar result in which forest age influenced species richness of carabid beetles in managed spruce stands and that younger forests possess a higher portion of generalist species, while older forests had species more adapted to the climax forest habitat. It was also seen that younger forests had a higher proportion of thelytokous species, capable of asexual reproduction and higher rates of population increase (Johnston 1996) and this was supposed to be a result of high level of disturbance (Palmer and Norton 1990) in these ecosystems. Thus, the distribution of soil microarthropods in an ecosystem depends on the management of soil ecosystem.

18.4.2 Methods to Manage Soil Ecosystems to Facilitate Proper Nutrient Cycling

The important role played by soil microarthropods in ecosystem management offers the possible option to manage the soil ecosystems so as to facilitate proper and efficient nutrient cycling. The most important option for management will be the addition of soil litter for increasing soil fertility. The addition of leaves on to the soil is a good option, as it can be acted upon by microarthropods to release the nutrients. In undisturbed ecosystems like forests, this is a natural phenomena while in ecosystems with human intervention like agricultural fields and home gardens, litter has to be introduced so that it can provide a good coverage to the soil. Mulching is a good option to increase the litter cover in managed soils, as it will provide a microhabitat for various species of soil microarthropods. The microarthropods like soil mites will cut the leaf litter into small pieces which can be acted upon by fungi and bacteria. This will help in increasing the soil organic carbon and will be helpful in reducing carbon dioxide in the atmosphere in addition to increased soil fertility. The fungivorous activity by collembola will contribute to reduced fungal population, thereby maintaining a proper balance in soil food webs, carbon and nitrogen cycle.

18.5 Soil Microarthropods, Nutrient Cycles and Climate Change

There are five factors of soil formation namely climate, parent materials, vegetation, topography and time (Brady and Weils 1999) and soils bear the signatures of these factors. Among the factors of soil formation, climate and parent materials give rise to great diversity in soil properties (Pettry 2005). Parent materials influence the nature/properties of soils and the minerals found in them while climatic factors affect the amount and speed of biological activity in pedoturbation. The macroscale perturbations in various ecosystems is a major problem to address at a global level. These perturbations are a result of anthropogenic activities, causing imbalance in ecosystem process. The serious outcome of these activities is climate change, which affects the various ecosystems and life activities of organisms. Climate change is the persistent, identifiable change in the mean and variability of climatic properties for an extended period of time (Okoruwa 2010). Soils are vulnerable to climate change because factors of soil formation are highly dependent on elements of climate and weather. The causes of climate change in relation with soils include greenhouse gases emitted from soils due to anthropogenic activities such as tillage and other forms of land use. Climate change can have direct or indirect effects on soil properties as they impact processes and products of soil formation.

18.5.1 Climate Change and Its Impact on Soil Ecosystems

Soils play pivotal roles in food production, nutrient recycling and waste management. However, the response of soils to climate change depends on several factors which include climatic variables (floods, rainfall, solar radiation, temperature and evaporation; soil properties (soil texture, mineralogy), population/activity of soil organisms, altitude and slope of sites (Hugo-Coetzee and Le Roux 2018). Since soil microbes are highly influenced by climate to soil quality and they are highly influenced by climate, soil pH, cation exchange capacity, base saturation, micro nutrients, hydraulic conductivity, porosity, bulk density and other physico - chemical properties are affected by the activities of soil fauna such as the microarthropods. According to (Bale and Hayward (2010), climate change affects the biophysical environment and consequently species biodiversity, phenology, distribution, composition and ecosystem functioning. Activities such as decomposition and mineralization intensity of organic matter are affected by climate change (Facey et al. 2017; Moss 2011). Climate change results in an increase in loss of soil organic matter due to higher rate of mineralisation. Organic matter is a cementing agent in the soil and its presence in higher concentration increases soil aggregate stability. The loss of organic matter increases the vulnerability of soils to degradation and changes associated with land use (Okafor 2016).

Climate change hampers nutrient cycling, presence, availability, uptake and utilisation of nutrients. Plant litter quality is reduced and this alters the concentration of nutrients released into the soil. Sometimes, the availability of nutrients become reduced due to leaching, mobility and immobilization of some nutrients, insolubilisation, occlusion of nutrient elements and soil depth at which the nutrients are found. The aforementioned conditions are worsened by the impact of climate change such as drought. Studies predict a decrease of soil moisture by 5–15% by 2080–2099, as a result of climate change (Dai 2013).

With climate change, vegetation and other biological factors become constrained, thereby affecting nutrient supply to the soil. The main attributes of climate change include high levels of carbon dioxide, increase in atmospheric temperature, abrupt changes in temperature, changes in wet and dry cycles, intensive rainfall, extended period of drought and heat waves (Qafoku 2015). These components of climate change have accelerated weathering of soil parent materials and increased carbon sequestration, transformation and mineralization (Facey et al. 2017).

Climate change directly impacts soil nutrient levels through its influence on nitrogen, carbon and phosphorus cycles and release of immobilized soil minerals. Microarthropods are ubiquitous organisms which contribute to soil quality through various bioengineering processes. Studies show that they have high adaptability to harsh environmental conditions as they can reestablish their community within 8 years after fire outbreak or bush burning (Goud 2017). But water-logging and drought result in anaerobic conditions and dehydration of soil, and hence pose a threat to soil faunal communities. Thus, climate change affects micro arthropod community structure, in addition to their physiological, biological and ecological functions.

According to Pareek (2017), moisture, temperature and carbon dioxide are important drivers of climate change and they affect soil processes and thereby, soil fertility and soil productivity. Climate change has led to higher rainfall levels in some areas whose effect on soil properties include leaching and erosion due to increase in run off (Brevik 2013). Other impacts of climate change on soils as listed by Akamigbo and Nnaji (2010), include reduction in soil biodiversity, excessive soil wetness, high soil temperature, depletion of soil organic matter, increased soil acidity, changes in soil consistence, desertification and loss of soil quality, salinity, flooding, soil compaction, surface crusting, alkalization, acid rains, deforestation and reduction in soil moisture, mineralization, evaporation and reduction in soil moisture. As bio engineers and active agents in pedoturbation, soil organisms contribute significantly to soil fertility, productivity and quality. The survival of soil organisms becomes limited in harsh environmental conditions like droughts and floods. Therefore, their population and activities such as burrowing, creation of soil channels, breeding and contribution to nitrogen cycles through excreta will be reduced. This leads to reduction in soil microbial population, reduced availability of organic materials and reduced decomposition rates which compromises soil quality (Nearing et al. 2004).

Increasing temperatures have led to higher loss of moisture from soils and plants through evaporation. High evaporation enhances the loss of soil moisture and in many cases lead to salinization of soils as the salt is retained on the surface of the soils. The amount and intensity of rainfall have increased due to global warming leading to higher erosion, soil erodibility, leaching and loss of clay and organic materials. With high rainfall comes higher rates of erosion and loss of soil materials. High rainfall and excessive wetness due to effects of climate change are responsible for the acidification of soils through loss of micronutrients and soil exchangeable bases. Another effect is the removal of surface organic matter cover of the soil through erosion, leading to increased soil alkalinity. Flooding associated with heavy rainfall can lead to large alteration in the properties of soils due to deposition of colluvium materials from the upper slope.

Soil weathering, soil carbon depletion, phosphorus and elemental cycling have been altered due to changes in climate and this has contributed to the adoption of new farming systems to mitigate the impact of climate change. With climate change and adoption of farming systems to mitigate climate change such as climate smart agricultural practices and intercropping models in the tropics to reduce moisture levels, there are modifications in Carbon and Nitrogen cycles (Gruneberg et al. 2014), which are favourable to soil ecosystems.

Soils support human and ecological systems through provision of water and nutrients for plant growth and human development, regulation of hydrological cycle and storage of carbon. Due to climate change, modification and changes in soil properties have introduced variability in soil physical, biological and chemical properties. Plant performance and ultimate recycling and supply of organic materials through leaf fall/decomposition and root exudation to soils have been altered (Abhilash and Dubey 2014).

18.5.2 Climate Change and Its Impacts on Soil Microarthropods

Soil physical properties such as porosity, permeability, bulk density, erodibility and texture affect the response of soils to various inputs and eventually soil productivity. Burrowing, pedoturbation, creation of tunnels and galleries in soils and addition of organic matter are prominent activities of soil microarthropods. Through decomposition of organic materials and decomposition of fecal materials gaseous exchange and aeration, porosity, aggregate stability, resistance to erosion and increase in capacity for nutrient storage and recycling are enhanced (Bagyaraj et al. 2016; Culliney 2013). Other soil processes influenced by alteration of nutrient cycles include soil microbial population, stability, plant-soil interactions and nutrient cycling (Karmakar et al. 2016). Organic matter grazing and excretion by soil microarthropods leads to an increase in the quantity of soluble organic carbon for soil nutrient production (Kardol et al. 2011). The important role of soil microarthropods in a functional soil ecosystem has long been identified and their role in nutrient recycling include decomposition, litter conditioning, incorporation of fecal materials into soil, degradation, mineralization and conversion of complex organic materials into various forms that can be uptaken by plants. In other cases, they secrete substances which solubilize complex and bound up phosphates. Through climate change, these activities, population and diversity of arthropods are altered which affect soil biogeochemical cycles through alteration and differentials response of arthropods to warming (Koltz et al. 2018; Amanda et al. 2018; Goud 2017). Decomposition of organic materials has been found to be delayed significantly by the absence of microarthropods (Parmenter and MacMahon 2009).

Through Carbon, Nitrogen and Phosphorus cycles, nutrients are constantly recycled in the soils through bioengineering and pedoturbation in which microarthropods along with other soil fauna are key players. Generally these three biogeochemical cycles are coupled for maintaining a healthy soil ecocystem (Delgado Baquerizo et al. 2013). Climate change causes a decoupling in carbon, nitrogen and phosphorus cycles, which affect the ecosystem functions (Penuelas et al. 2012; Reynolds et al. 2007; Schlesinger et al. 1990). Soils' ability to store and release nutrients is a function of its nutrient cycles. As organic matter and clay are the main store houses of soil nutrients, the nutrient availability and retention depends on the nature and properties of clay minerals and organic matter. After the introduction of organic materials to the soils, micro arthropods are responsible for the physical breakdown of organic materials to inorganic forms. This leads to the enzymatic polymerization of organic matter into particulate organic forms. Further action by soil microbes and micro arthropods lead to the mineralization and transformation of complex organic matter such as polymeric Nitrogen which is converted into bioavailable, monomeric and dissolved organic forms. The other soluble forms like organic carbon, available ammonium, nitrate etc. can be easily up taken up by plants. Low availability of soil nutrients such as nitrogen are major constraints to sustainable cropping systems and the breakdown of organic materials into assimilative forms by plants is the main ecological advantage of nutrient recycling. With the influence of climate change on plant growth and variation in the activities of micro arthropods, there is no proper regulation in the quantity and quality of organic materials that enter the ecosystem through the carbon, nitrogen and phosphorus cycles (Yang and Gratton 2014) as plant biomass production and the activities of micro arthropods such as breakdown of organic materials are affected.

18.6 Research Gaps in Nutrient Cycling Related Microarthropod Research

Soil microarthropods and their relationship with nutrient cycling is an interesting topic to be addressed. But there are many research gaps which limit the knowledge on the role of soil microarthropods in nutrient cycling. The most important research gap is the knowledge about soil microarthropods itself. The species wise distribution of soil microarthropods and the importance of each species with soil biogeochemical cycles is not properly explored. This limits the detailed understanding the role of each microarthropod community in the soil ecosystem and their importance in sustaining the soil ecosystem through their role in biogeochemical cycles. Decomposer ecology are not well characterised for soil organisms, Which involves life history strategies, the relationships between organisms and their contribution to ecosystem functioning (Crossley et al. 1992). The functional classification of soil microarthropods is not well addressed and more research is required to identify the various microarthropod functional groups as functional approach is always more suitable for studies related to biogeochemistry than taxonomy-related approach and for this, the functional role played by each microarthropod fauna needs to be identified. The most important drawback which restricts regional and comparative studies on microarthropods is the lack of a proper database for region-wise information on soil microarthropods. This is a major problem which hinders the upcoming research in this area. Another drawback is the absence of species-based laboratory and field studies to understand the role of soil microarthropods in nutrient cycling and climate change related aspects. The overall relationship of microarthropods to various trophic levels needs to be addressed to precisely determine their role in soil ecosystem functions like litter decomposition and biogeochemical cycles. This has to be developed by involving a combination of lab and field related approach which requires more time and creation of complex experimental designs.

18.6.1 How Can the Research Gaps Filled?

The research gaps in microarthropod related research needs to be reduced to study the relationship between soil microarthropods and biogeochemical cycles. For this, an understanding the species wise distribution of microarthropod fauna is essential. Expertise in this area can be developed through proper training and developing keys for each group of microarthropod fauna. Internet based interactive keys will help the researchers to understand the basics about microarthropod taxonomy. The identification and functional classification of microarthropods in soil ecosystems will help for the detailed understanding of soil microarthropod fauna into various functional groups and help in defining the ecological role played by each functional group in the biogeochemical cycles. Creating a database for soil microarthropods in the world will be a good initiative for encouraging more research on microarthropods. A world map with georeferenced points with details of microarthropod fauna will be much helpful to trace the geographical distribution of microarthropod groups. With more research initiatives focused on single species and functional groups, the importance of various microarthropods can be well studied and more relationships can be established. This will also add to sophisticated, ecofriendly farming models and management measures to combat climate change.

Acknowledgements The first author thank School of Environmental Studies, CUSAT for providing facilities for conducting research. The work was completed with the financial support from UGC in the form of UGC SRF fellowship from Government of India.

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Chapter 19
Environment, Climate Change and Biodiversity

Zia-ur-Rehman Mashwani

19.1 Introduction

Climate is a long term, usual prevailing weather condition in a specific area of earth. Climatic conditions in different areas determined by rainfall intervals, amount of precipitation, wind velocity, wind pressure, humidity percentage, sunshine, cloud formation and others meteorological events such as thunderstorms, windstorms and snowstorms. These all events collectively responsible for determining the climatic condition. Climatology basically related with the geographical position of area on earth. Geographic location include distance from ocean, sea or coast, altitude, latitude, and also mountain ranges which are also responsible for changes in wind direction. Variety of flora growth, development, morphology and reproduction are visible sign for specific climatic conditions. Climatic conditions also responsible for adaptations. Animals lived in different areas behave differently and adapt different ways for living, feeding, and reproducing. Climatic conditions strongly affects the human lives and also determine the different cultures and traditions in areas. So we can say that climate affect each aspect of plants, animals and human lives. Basically six major climate discussed on earth.

- Tropical areas
- Temperate areas
- Polar regions
- Arid zones
- Cold tundra
- Mild Mediterranean

These six are major climatic systems and each have different environmental conditions. So the Biodiversity in these systems adapted in a different way. Climate is

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_19

usually long term environmental condition in definite area but now in modern age many human activities are responsible for changes in natural climatic conditions like industrialization, greenhouse gases, deforestation, land cutting, changes in slops and natural flow of water for commercial purposes.

19.1.1 Six Different Climatic Systems

19.1.1.1 Tropical Regions

These regions are exist in middle of equator and have suitable climatic condition but temperature usually remain high throughout the year. Africa, Asia, North America, South America and Australia, Amazon basin, Congo basin, rainforest of Malaysia and Indonesia are included. Soil in these regions are more fertile for growth of different plants. Mountain in these areas remain cover with snow all year but in summer large amount of water fill sea and ocean. Summer in some areas is too much hot like Asia, Africa and North America. Soils in tropical regions are favorable for growth of major crops like wheat, rice, corn etc. These areas have luxurious vegetation's. Different kinds of animal species inhabitants in tropical regions.

19.1.1.1.1 Tropical Environment

Usually rainfall 1000 mm yearly and 60 mm averagely noticed per month (Wambeke 1992). Fortunately four seasons available in these regions. Summer is too hot in these regions and duration of summer is long than winter especially tropical deserts. Dew drops are only source of water for shrubby vegetation's. In these areas temperature rarely fall below 65 Fahrenheit. Seasons are either dry or rainy. Mostly temperature remain constant throughout the year.

19.1.1.1.2 Tropical Rain Forest

There is large pasture areas available for grazing animals. Annual rainfall is above 1000 mm yearly makes vegetation more flourished and also proper temperature available to plants growth and development. All tropical forest are not rainforest, some areas receive low amount of rainfall yearly especially in summer. Winter produce heavy rainfall which flourishes vegetation's. Epiphytes, orchids, palm trees, rubber trees, giant water lilies, and jaguar is special living creatures in these regions (Reiners et al. 1994).

19.1.1.1.3 Tropical Grassland

Africa is a famous for grasslands. Large grasslands are also exist Australia, South America, Colombia, and Indian plateau. Areas with variety of plants trees, grasses, flourishes vegetation's. Three major grasslands in world savanna grasslands, prairie grasslands, steppe grasslands. These regions receive 500–900 mm rain yearly. Temperature range between −20 and 30 degree (Dlamini et al. 2014).

19.1.1.1.4 Tropical Deserts Properties and Specialties

The deserts in these areas have very harsh climate and very hot summer throughout the year. The plants in these regions are cacti, saguaro cactus, weathered trees, tumbleweed, wildflowers are very common existing species (Sánchez and Cochrane 1980) (Fig. 19.1).

19.1.1.1.5 Tropical Regions Common Diseases

Tropical regions have many cases of epidemic which destroyed large community in history such as malarial disease sign are also found in ancient Egyptians mummies. Dengue, yellow fever, filariasis, common in Africa and Southern America. There are others many disease are present in these rural areas but neglected by world like African sleeping sickness disease, rabies, leprosy, guinea worm disease, cholera, lymphatic filiariasis. Many developing countries in these regions have no availability of proper vaccine, medicines and treatments. There are large number of population affected by these aliments and epidemics and finally death (Hotez et al. 2007). Most countries of Africa and Asia are considered as developing countries so low quality food and food products and no proper provision of drinking water to communities are major reason of aliments in these regions. Different agencies and societies work in these areas in field of health and food security but major program needed for development of these regions.

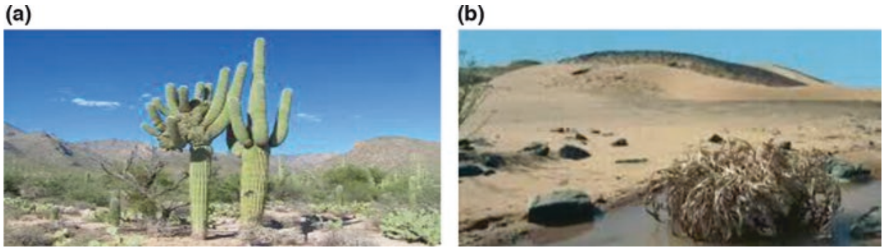


Fig. 19.1 The respresentatiove plants of tropical deserts. (**a**) Saguaro plant. (**b**) Tumbleweed plant

19.1.1.1.6 Tropical Areas Human Adaptations

I. Rainforest are basically the home of native tribal people. They depend on their surrounding for survival and to full fill basic needs of routine life. But due to cutting of more and more trees is the main reason of forest destruction, but their government have no hold on these people.
II. People live in tropical deserts face more difficulty than any others. They live in small huts face shortage of water whole year. They totally depend on herds of animals and camels for food and transport. In Pakistan Cholistan desert, Rohi desert, and Thar and Thal and Rajistan in India are popular for their harsh environment.
III. People live in cold tropical areas face less difficulties than any other because in summer luxurious fruits and vegetation's and crops variable. No shortage of food and water. Crops growth is highs in these areas.
IV. Rain forest in tropical are very thick, flourished and evergreen vegetation's grow here. Only tribal people live mostly in these areas. No shortage of water and scarcity of food here (Table 19.1).

19.1.1.2 Temperate Regions

Temperate regions lie between tropical and polar regions and cover approximately 7% of world. Climatic conditions are normally moderate no severe burning not freezing. Mostly these areas have four seasons summer, autumn, winter and spring. Temperate regions include Europe, Canada, Sothern Australia, Central Asia and Southern South America. Unpredictable rainfall, fog, snow, and storms are common characteristics of these areas. Soils are fertile and good for plants growth but remained cold for long period of the year. Winter months are too much cold for ripening of crops but summer is hot enough for ripening of wheat, rice, sorghum. Weather conditions are not remained stable in these regions (Whitehead 1970).

19.1.1.2.1 Temperate Environment

Temperature in temperate areas is not at extreme caused no burning and not too much cold. So environment in these areas is more flourished and favorable for life. Four seasons in a year autumn, spring, summer and winter makes them more luxurious. Precipitation fall in form of rain or snow. Amount of precipitation fluctuates in Washington and Seattle. In rainforest precipitation rate is above 137.79 inches annually. In some areas rainfall is above 78.74 inches (Delpla et al. 2011) (Fig. 19.2).

19.1.1.2.2 Temperate Rain Forest

Temperate rain forest start from Alaska to northern California in North America. Temperate rain forest located near the costal line of United States, Norway, Japan, New Zealand and South Australia. Difference between tropical and temperate rain

Table 19.1 Tropical region animals, plants, and their adaptations

Tropical regions	Species name	Picture	Adaptations
Tropical desert	Chile llama		Found in Atacama desert. High concentration of hemoglobin in blood help to survive at high altitude.
Tropical evergreen forest	Jaguar in rain forest		Jaguar is a good swimmer and fur camouflage helpful in predation.
Tropical plants	Palm tree		Palm tree leaves is an adaptation, protect from drought, heat and cold.

(continued)

Table 19.1 (continued)

Tropical regions	Species name	Picture	Adaptations
Tropical plants	Durian fruit		Jackfruit effectively grow in these areas because of large water supply and mineral content.
	Giant lilies		Thick cuticle protect from desiccation, and enhance photosynthesis, and also protect fishes in water.

Fig. 19.2 Temperate forest in South America

forest is that tropical rain forest are warm and humid and have high moisture content but in case of temperate rain forest are moist, humid but cool (Kitching et al. 1993). Only woodlands in temperate rain forest receive heavy rainfall large numbers of trees grow in these forest compared with tropical rain forest. Only small portion of tropical forest are rain forest (Kikkawa 1966).

19.1.1.2.3 Temperate Grasslands and Woodlands

Basically 4 major grassland in temperate regions. Temperate grasslands have cold winter and hot summer. Major grasslands includes veldts of Africa, pampas of South America (Argentina), steppes of Eurasia and plains of North America. These regions have heavy rainfall and have many types of trees (Prober and Thiele 2005). In grasslands trees are dominated over grasses (Poaceae). Summer is hot in these regions some time high as more than 100 Fahrenheit but this is not caused burning so vegetation's remained flourished approximately whole year. In summer rainfall also occurred but average is low than winter. In winter heavy rainfall makes soil more porous and enhance nutrient content. Temperature vary from low to −40 Fahrenheit (Martin-Neto et al. 1998).

19.1.1.2.4 Temperate Regions Common Diseases and Humans Adaptations

Temperate regions usually have cold climate. Some diseases are common hepatitis B, influenza A, measles, asthma, pertussis, tuberculosis, rotavirus, tetanus, syphilis are common diseases which prevail in these countries. Respiratory diseases are common in these regions. Death rate due to epidemic is low in these areas as compared with tropical regions. Most areas have temperature 0 degree to 28 degree which is not sever in most cases. But seasonal fluctuations are common in these regions fogy storm some time destroy whole cities and seasonal rains some time change in to storm and are reason of sever destruction for crops and infrastructure (Van Dijk et al. 2010) (Table 19.2).

Table 19.2 Major plants of temperate climate

Northern America deciduous forest	Species	Adaptations
Quercus rober (Oak plant)		There are many variety of oks are found in temperate areas, evergreen leaves, fruit ripe after 2 years, female flower covered with scales and protect food. Male stamens born on same plant. Many species are highly poisonous.
Fagus grandfolia (American beech)		Use for timber and ornamental purposes, leaves of American beech are blue green, 13 cm long, trees are 30 m long, deciduous tree, also grow for ornamental purposes in lawns and gardens.

North temperate zone (Japan)		
Acer saccharinum (Silver maple)		More than 200 species, basically grown for ornamental purposes due to different shaper of fruit. Important for maple syrup. Berries use in medicines. Winged seeds lobed leaves.
North America, Greenland, Iceland's, Europe		
Carya avata Shagbark hickory		Grows in North American deciduous forest. Use for ornamental purposes, large and evergreen leaves, wood used for furniture. Long trees above 100 m.

(continued)

Table 19.2 (continued)

Northern America deciduous forest	Species	Adaptations
Liriodendron tulipifera (Tulip tree)		Important North American timber tree, height is 60 meter, also known by white popular and yellow popular. Grow for its beauty long straight stem with oblong crown.
Nyssa sylvatica (Black gum)		It found in moist area of US, Maine south, gulf coast and Oklahoma, wood is light in weight and strong enough,

Taxodium distichium (Black cypruss)		Valuable wood because of water resistance, very beautiful foliage. About 100 ft. long trees, but due to wholes in wood fungus can easily destroy wood..
Eucalyptus globulus Eucalyptus trees		Largely plantation in Australia. Basically grows shading, as a forest tree. Major plants in temperate forests.

19.1.1.2.5 Temperate Regions Biodiversity and Relationship with Their Environment

I. Temperate regions are famous for its cold climate. People in these areas are adapted according to their environment. Adaptations vary according to their climatic conditions such as in north America people face strong cold and wear thick dresses as compared with native tribes in temperate rain forest where even winter is not too much cold (Galicia et al. 2015).
II. People lived in hilly areas faced severe winter, everything change in to ice .life tough in these areas.
III. Due to different climatic conditions cultures, traditions are different among people.
IV. Environmental conditions are favorable for agriculture.
V. People in these areas have close relationship with their environment (Swarts et al. 2017).

19.1.1.3 Polar Regions

Arctic, Antarctic, Siberia, Northern Canada located at high latitude. Land in these areas cover with snow and darkness throughout the year. Temperature fall as low as −80 in Antarctic and −50 in Artic which is severally low for life. Average rainfall is low annually 250 mm yearly which makes them dry as deserts hot areas. Soils in these areas are too much cold for plants growth and remain covered with snow whole year. Only those plants can grow in these regions which have high content of anti-freezing proteins bearberry (fruiting plant), pasque flower (flowering plant), Artic willow (dwarf shrub) but mostly algae, lichens, mosses grow here. Only those animals can survive here which hibernate 6 month of winter like polar bear, or those live which live in water like seals and other fishes survived in these cold water because of presence of unsaturated lipid bilayer which protect them from freezing (Chilali et al. 1999).

19.1.1.3.1 Polar Regions Characteristics

Polar climate are characterized by lack of summer, no warm month in whole year. Summer is cool in these regions sun is on horizontal position so heat intensity is very low but the winters are dark and bitterly cold. Each month have temperature below 10 degree. Soil is cover with thick are thin layer of ice during whole year. So glaciers, tundra treeless regions are included in it. Cool to cold environment exist here. Very complex plants and animals in these regions. Slops, slides, elevation above sea level (Gow and Tucker 1990) (Fig. 19.3).

19.1.1.3.2 Artic Regions Characteristics

These regions located in northern most region of earth. Exist in latitude 65.5 north direction of equator. Arctic regions are overall covered with water which is in frozen state. Summer is cool but winter is bitterly cold in these regions. Soil remain frozen all

Fig. 19.3 Arctic climate and environmental conditions

the year and germination of normal flora is impossible due to very low temperature of soil. This makes conditions of arctic tundra. Arctic regions not only the hose of unique species like polar bear but also large frozen white area on earth reflect the sun rays and help in balancing the earth temperature (Zoltai and Vitt 1995). Other than this these areas are the house of unique animals like polar bear, dog fish, snow fox etc.

19.1.1.3.3 Importance of Arctic Regions

Arctic regions play an essential role to control global warming and maintaining earth temperature. Large white ice frozen area reflect the sun rays from earth surface and protect to penetrate in earth surface but humans activities are major reason for destruction of habitat lead towards the global warming. Soil temperature continuously elevate and this increase is a major reason of melting ice in polar region and glaciers (Walsh 2008) (Table 19.3).

19.1.1.3.4 Antarctic Regions Characteristics

Antarctica is the highest, coldest, driest region on the earth. Highest peaks 4000 m are located. Mt. vision is a part of Ellsworth Mountains located in western continent in Antarctic Peninsula. Antarctic region have highest mountain due to these this regions is consider highest continent in the world, it is because of thick layer of ice. East area have thicker ice sheet and low underlying row of rocks than west side have more rocks bed and thin ice sheet. It is the world coldest and driest part of earth with very low precipitation (Fernandoy et al. 2012). Due to low precipitation it is consider as polar desert. Only 0.32% area is glaciers free but these island exist between large mountains of ice. These coldest areas are very precious for our earth because they balance our earth temperature against sun rays (Aristarain et al. 1990) (Table 19.4).

19.1.1.4 Arid Zones

These areas faces sever dryness and water shortage. World biggest desert Sahara, Gobi desert, Arabian Desert and large area of Iraq, Northern China, and Cholistan at boarder of India and Pakistan also included in arid zones. Rainfall is below

Table 19.3 Plants in polar climate

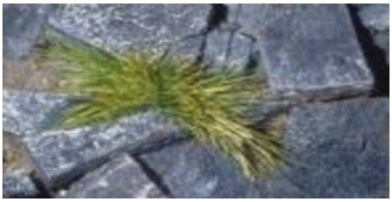
Artic region plants names	Species	Adaptations
Salix arctica Arctic willow		Dwarf shrub, food foe caribou, musk oxen, and native people called this plant tongue.
Pulsatilla vulgaris Pasque flower		Found in northwestern united states and northern Alaska. Body covered with fine silky hairs which protect against ice hazardous.
Arctostaphylos uua-ursi Bearberry		Leathery evergreen leaves, body is covered silky smooth hairs, these berries are called bearberries because bears like to eat.
Saxifraga oppositifolia Purple saxifrage		Grows in low light and tight hard soil areas, small star shaped flowers appear from melting snow.
Papaver radicatum Arctic poppy		Plant height is 10–15 cm, one flower on each stem, flowers turn their direction towards sun.

(continued)

Table 19.3 (continued)

Artic region plants names	Species	Adaptations
Eriophorum angustifolium Cotton grass		Name for its fluffy flowers, cotton grass are important food ingredient for migrating snow geese's.

Table 19.4 Antarctic regions plants

Antarctic regions plants names	Species	Adaptations
Deschampsia antarctica Antarctic hair grass		Grow in tough and hard rocks and absorb nutrients. Source of food for Antarctic animals.
Antarctic lichens		Lichens are association between algae and fungi, cn grow in hard environment because can perform photosynthesis.
Red algae		Look like plant, is a major source of food for aquatic animals.

(continued)

150 mm annually and when rain do fall caused flash floods. So very strong winds and dirt storms. Temperature reached at 0 C at nights and above 50 C during day-time (Rapport and Whitford 1999). Southeastern Arizona disturbance of vegetation due to no rainfall occurred till centuries (Bahre and Shelton 1993). Most vegetation's are dwarf shrubs and plants with deep stomata, tough cuticle layer protect them from transpiration, mostly plants adapted themselves and reduce leaves to spines, all those strategies are adapted by plants which protect them from desiccation. Grasslands are consist of shrubs (Whitford et al. 1995). Animals lived very tough life and faced scarcity of food and shortage of water whole year, Sahara elephants, wilder beat etc. they travel long distances for water and food sources. Shrubby vegetation's and dwarf trees are only source of food.

19.1.1.4.1 Desert

Deserts is a part of earth which receive very low amount of rain fall, less than 250 mm annually. Approximately 1/3 part of earth is included in deserts. There are 25 deserts in different continents of world. There are 4 major kind of deserts (1) cold winter deserts (2) cool coastal deserts (3) subtropical deserts (4) polar deserts (Tables 19.5 and 19.6).

Table 19.5 Major five deserts in world

Deserts name	Characteristics
Antarctic desert	Antarctic desert is world largest polar desert. It cover approximately 5.5 million square miles. This region receive very low or no precipitation. Very large slop and mountain exist in this desert these are formed due to thick ice sheet small rock bed.
Arctic desert	Arctic desert is the second largest desert of world. It covered approximately 5.4 million square miles. There are many countries include in this desert Canada, Norway, Russia, Iceland, Greenland, Sweden, Finland.
Sahara desert	This is the third largest desert of earth. This is a subtropical desert in Northern Africa. Area extended more than 3.5 million square miles. Hard and tough climate. No rainfall do even many years. Only dwarf shrubs and arid regions plants. Dew drops is only source of water for plants.
Arabian desert	Located in Arabian peninsula is a subtropical desert. It covered one million square miles area. Also have very harsh climate. Very low rainfall if rainfall do it is only flushes. Only shrubby vegetation's are found grow here. During night temperature fall and sometime reached at 0 degree but days are too hot.
Gobi desert	Gobi desert is a cold desert covered area of 500,000 million square miles. In winter temperature reached at −40 degree and in summer 45 degree. Temperature in this region at great extremes.

Table 19.6 Major deserts plants

Plants names	Species	Adaptations
Saguaro cactus		Found in Sonoran desert of Arizona. Mysterious plant, without leaves, bloom in summer and its flower are national flower of Arizona
Baseball plant Euphorbia obesa		Found in Karoo desert of south Africa have similarity with baseball so names baseball plant. This has become extinct in nature because of more collection.
Silver torch desert		This plant is also known as wooly plant and have 2 inch long spine, grow at −10 degree, very beautiful in structure.
Barrel cactus		Native to southwestern America, grow till 10 m in height, have shallow root system. Yellow color flower appear on head. This plant can survive 150 years in harsh environment.

(continued)

Table 19.6 (continued)

Plants names	Species	Adaptations
Desert ironwood		This plant only food in Sonoran desert on north America. This plant also have ability to drop temperature around environment, shad their leaves when temperature too much increase.

19.1.1.4.2 Arid Zones in Pakistan

Cholistan is a major desert cover the area of Bahawalpur, Bhawalnagar, Rahimyar khan (Akhter and Arshad 2006). Indus valley desert located in northern area of Pakistan. Kharan desert area found in northeast Baluchistan. Thal desert located in Mianwali area between Indus and Jhelum River. Thar desert located in province Sindh (Enright et al. 2005).

19.1.1.5 Cold Tundra

Tundra mean treeless regions. Two types of areas consider in tundra Alpine tundra and Arctic tundra. In these areas soils are called gleisoil's low nutrient soils are frozen enough for germination of seeds. These regions are located at high latitude. Frozen soil only support growth of lichens, mosses, dwarf shrubs, and wildflowers. In tundra animals popular one is muskox, arctic wolf, snowy owl, and arctic squirrel (Rocha et al. 2012).

19.1.1.5.1 Cold Tundra Plants

There are basically three tundra regions (1) Arctic tundra (2) Antarctic tundra (3) Alpine tundra.

19.1.1.5.2 Arctic Tundra

Region occur in northern hemisphere in taiga belt. There are treeless plains. Major area of Russia and Canada include in it (The tundra biomes 2006). Several people live in these areas Nenets and Nganasan tribes. Winter seasons are cold and dark temperature in winter −28 and as low as −50 degree. In summer temperature 12 degree. Flora mostly consist of mosses lichens, and algae (Higuera et al. 2011).

19.1.1.5.3 Antarctic Tundra

Antarctic tundra basically consist of Antarctic regions. South Georgia, Sandwich Island and Kerguelen Island. Only support driest vegetation's like mosses algae and lichens (The terrestrial plants 2006). These regions are home of many animals major like polar bear, seals and penguins (Antipodes Subantarctic Tundra Island 2009)

19.1.1.5.4 Alpine Tundra

These regions are also located at high altitude and similar to polar climate because if no trees growth at high altitude. These regions are cold due to low air pressure. Alpine tundra differ from polar tundra because soils are better drain. Vegetation's like mosses, lichens, sedges, perennial grasses (Körner 2003).

19.1.1.6 Mild Mediterranean

Part of the earth around Mediterranean Sea is known as Mediterranean regions. 22 countries surrounded the Mediterranean Sea. Mediterranean countries includes north shore linked with Italy, japan, France, Spain, Bosnia, southern shore includes Morocco, Algeria, Egypt, Tunisia, Libya (Brun et al. 1998). Summer is hot and dry in these regions and mild and rainy winter. Soil is mix type but have high nutrient content, annual plants dried out during summer due to sever dryness but winter makes soil porous (Yaalon 1997). Rate of precipitation is 20 inches yearly. Summer is severely dry but winter is rainy. Crops growth is good in these regions but dry areas have shrubby vegetation's thyme, rosemary.

19.1.1.6.1 Mediterranean Regions and Climatic Conditions

Mediterranean climate is between dry hot summer but mild and wet winter. Climatic conditions is not sever in these regions. Mediterranean ocean directly affect their climate. Diurnal temperature variations. Days are hot and dry but dusk time rapidly cooling start. Precipitation rate is higher during winter but no rainfall during summer for 3–6 month. Rate of evapotranspiration is higher in day time. Rainfall is not evenly distributed in these regions like Barcelona and Los Angeles experience very hot and dry summer but now frost and snowfall in winter but in Tashkent winter have annual snowfall and frost. But in Athens have very high temperature even 48 degree in summer. Los Angeles have mild climatic conditions like 21 degree normal temperature even in summer ("España a Través de los Mapas". *www.ign.es*.).

Table 19.7 Major vegetation's in mild Mediterranean regions

Herbs	Penstemon, dietes, achillea
Grasses	Bunchgrasses, sedges, rushes
Shrubs	Rosemary, banksia, chamise
Trees evergreen trees	Cypress, pine, bay laurel,
Deciduous forest	Sycamore, oak, buckeyes

19.1.1.6.2 Vegetation's in Mediterranean Regions

Basically seven types of vegetation's are found in these regions and their growth is supported by environment (Dallman 1998) (Table 19.7).

19.2 Climatic Changes and Biodiversity Destruction

This earth is precious for humans because this is the only planet where all environmental conditions is suitable for human life along with animals and plant life. Environmental conditions on others planet do not support our biodiversity. But this beautiful home destroy by humans only. Changes in climate refer to anthropogenic climate change (Bodansky 1993). Term climate change related with anthropogenic climate change. Major disturbance is caused by global warming. Earth temperature is continuously increase due to human activities. There are some major factors involve in climate changes.

19.2.1 Global Warming

In modern world human activities severely damage the earth natural processes. In anthropogenic activities green house is really important to discuss. In green house sunrays are absorb but do not reflect back. So this is the major reason to elevate the earth temperature. These four gases concentration elevate constantly (1) methane (2) carbon dioxide (3) nitrous oxide (4) fluorinated gases. Oil, coal and gas like methane burring, elevate carbon dioxide content in atmosphere. Excessive use of nitrogenous fertilizers elevate nitrous oxide content in atmosphere. These gases enhance environmental temperature. In last two decades earth temperature elevate 2 degree. This is critically dangerous for all life forms on earth (Meinshausen et al. 2009; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b).

19.2.1.1 Greenhouse Effect

Greenhouse effect by definition is less transparency of our atmosphere and different types of toxic gases covered our atmosphere around earth, so sunrays are not reflect back and absorb on earth surface and propagate heat around all direction. These gases includes chlorofluorocarbons, methane, nitrous oxide and specially carbon dioxide (Broecker 1975).

19.2.2 Changes in Natural Path of Water for Infrastructure Development

Changes in natural flow of water by cutting land for infrastructure development but these changes are major reason of land degradation, flooding and also decrease soil fertility. Floods destroy large population in different countries because humans tried to change natural water routes, resources, and natural flow of rivers and streams according to their own designs (Weitzman 2009). It is time to need sustainable infrastructure. Its mean that infrastructure development don't affect ecologically, socially and economically (Oztas et al. 2013).

19.2.3 Changes in Pattern of Rainfall and Threat for Agriculture

Climatic changes are mainly related with anthropogenic activities of humans like deforestation, release of fluorinated gases, nitrous gases, methane, carbon dioxide, industrialization are factors which majorly contributed in temperature elevation, variations in rainfall patterns, storms and drought (Mendelsohn 2014). These problems are sever especially in developing countries because government have not enough capacity to mitigate these issues (Kurukulasuriya et al. 2006). Changes in pattern of rainfall and as a result in drought on large fertile land in Asia and Africa. Shortage of water for agriculture researcher predicted that wheat yield in south Asia will decrease 50% by 2050 which is 7% of global wheat production (Arnell et al. 2004). Sub-Sarah Africa and south Asia are sever hungry areas of world (Vermeulen et al. 2012). In south Asia variations in rainfall pattern either caused drought situation or in other case floods in many areas destroy and washed away whole fields. Farmers in developing countries face more trouble because government provide no fun and support for rehabilitation (Droogers and Aerts 2005).

19.2.4 Heavy Industrialization

Sunrays are come from sun some reflect back and some absorb on earth surface but the problem is raised due to excessive release chlorofluorocarbons, carbon dioxide and methane gases (Lockwood 2009). These gases absorb sunrays and propagate heat in all direction but recent researches show that these gases excessively released from heavy industries due to burning of coal, oil and methane gases**.** Industrialization in recent decades has become a major and critical problem and a reason of climatic changes but also fill soil with heavy metals and toxic chemicals which prohibited the growth of many plants and animals species leads many areas towards desertification (Lean 2010).

19.2.5 Deforestation

Deforestation not only leads towards lessens of trees but also the stores carbon dioxide released from dead plant body to environment. Carbon dioxide is a major greenhouse gas and its higher concentration is a serious threat for earth environmental stability. Elevation in concentration of carbon dioxide because trees use this gas in photosynthesis but lessens number of trees and large amount of carbon dioxide is a serious threat. There are some major reason of deforestation

I. Woods used in paper industry
II. Cutting of trees for furniture and for home decoration.
III. Wood is also used for wood oil like pine trees.

For restoration of environment basically efforts needs diminish the excessive quantity of carbon dioxide and to buildup wildlife habitat (Bradford 2018).

19.2.6 Disappearance of Water Bodies

Disappearance of water bodies (lakes and rivers) dried up in many areas of world. Climatic disturbance change rainfall pattern and due to less rainfall and due to high temperature evaporation rate increase and this leads to sever desiccation. Chad Lake, rivers in Africa, Asia and Middle East, Aral Sea in border of Kazakhstan and Uzbekistan and list is not end up here. Waste area in Pakistan also damage. Dams and water extraction from rivers through canals are also a major reason for water sources disappearance (UNEP GM 2002).

19.2.7 Oceanic Acidification

Oceanic acidification is a burning issue in these days. Many anthropogenic activities are only responsible for this problem. In recent decades industrialization and agricultural reforms buildup human life style and decrease the scarcity of food for humans along with animals but humans are also responsible for destruction of natural ecosystem. Burning of coal, gases and oil elevate carbon dioxide concentration in air and when oceanic surface touches atmosphere and also acidic rains these carbon dioxide mix in oceanic water. Then a chain of chemical reactions occurs and carbonic acid. High concentration of hydrogen ion decrease level of carbonates. These carbonates are important in calcification and shell formation in sea shells, oyster, corals and calms. Due to disturbance of optimum ph. and increase acidification dissolves calcium shells and in some cases inhibit the formation of shells in corals. In some fishes it damage fish normal development (Shafeeque et al. 2017).

19.3 Climatic Changes and Threats to Biodiversity

19.3.1 Temperature Elevation

Constant increase in temperature is an alarming situation for survival of biodiversity. Decline in rate of reproduction of many species of animals and plants because environment cannot full fill the requirement of optimum temperature. Green ringtail possum in Queensland cannot maintain its body temperature if environmental temperature increase from 30 degree. But now this is an endemic species (Laurance 1990).

19.3.2 Bleaching of Coral Reefs

Bleaching of coral reefs, is due to high temperature corals expel zooxanthellae outside their body so corals loss their color. Zooxanthellae and corals makes mutualistic relationship. Algae provides nutrients and proteins to corals and zooxanthellae provides oxygen to corals to remove waste. Due to removal of algae loss of pigmentation, nutrients. Those corals which loss zooxanthallae is not able to perform photosynthesis, no photosynthesis no food preparation. So death of coral (Hoegh-Guldberg 1999).

19.3.3 Changes in Rainfall Patterns

Changes in pattern of rainfall severely affect aquatic life of earth. For example Australia is is dry continent but have variety of fauna and flora. Changes in rainfall pattern alter water quality and quantity but also leads towards extinction of many species like Australian kangaroo's. Macquarie marshes are home of many species like water birds, turtles, and whales which are at high risk (Memmott et al. 2013).

19.3.4 Higher Concentration of CO_2 in Water and Plants Growth

Higher concentration of carbon dioxide is harmful in water bodies harmful for aquatic life. Higher quantity of carbon dioxide caused eutrophication and microalga growth lower the oxygen content. Rainwater flow fertilizers from field, phosphate and nitrates to water bodies is a major reason of eutrophication (Riebesell 2004). Higher concentration of carbon dioxide produce algal bloom over entire surface of water bodies and depleted the nutrient concentrations for other organisms and also inhibit sunrays to reach to flora in water depth (Rixen et al. 2012).

19.3.5 Rise in Sea Level

Global warming is a burning issue now a days. It has become a severe problem for ice caps and glaciers in last decades. Researchers estimate that glaciers will completely melt in 2035. The rate of ice caps melting is quicker than snowfall deposition. The rising in sea level is the result of melting of glaciers and ice caps. Ices caps are critically important for balancing earth temperature because there ice structures reflect sun rays from earth surface along with diminish the heat waves effect in all directions (Church et al. 2013). Oceanic heating in different parts of earth contributing in sea level elevation like Antarctic regions store 70% of world fresh water (Winkelmann et al. 2012). World highest contribution in increase of sea level is found in East Antarctica (Fretwell et al. 2012). West Antarctica, sea ice and glaciers are at hiher risk of melting as a results of global warming.

19.3.6 Adaptations of Organisms Against Changing Environmental Conditions

19.3.6.1 Adaptations of Plants

I. Elevation in temperature due to global warming many plants species short their life cycle because high temperature makes pollens unable to fertilize ovule so plants start early reproduce and complete their life cycle in spring before summer heat start.

II. In Arctic regions plants start to migrate towards higher latitude and altitude because their native environment is not support their life cycle (Aldrich et al. 1998).
III. Hybrid plant species survive more effectively in changing environment than parent variety.
IV. Many plants species have more thick cuticle layer than before to protection against desiccation (Jump and Penuelas 2005).
V. Many plants species starts to reduce their expansion because of difference in continental and oceanic environment temperature in northern regions (Crawford and Jeffree 2005)**.**

19.3.6.2 Adaptations in Animals

I. Elevation in temperature and scarcity of food, animals starts to move towards higher altitude and latitude (Cho 2015).
II. At Australian coast sea turtles gender transformation has become a serious issue. In case of lower temperature eggs embryo develop in female but in case of higher temperature of environment eggs develop in to females, researchers observed 99% female turtles, this is a serious dander for species survival (Besnier et al. 2014).
III. Oceanic corals starts bleaching and loss their color because they expel algae which make mutualistic relationship with corals due to low nutrient supply and higher temperatures. These corals are home of variety of aquatic life (Perry et al. 2018).
IV. Epigenetic changes in guinea pig like their ancestor produce phenotypic changes according to environment needs but due to change in environmental sequences the changes as such transfer to next generation without change. So next generation's loss ability to transform themselves according to environment requirements (Weyrich et al. 2016).

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Chapter 20
Consequences of Salinity Stress on the Quality of Crops and Its Mitigation Strategies for Sustainable Crop Production: An Outlook of Arid and Semi-arid Regions

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Abstract One of the key tasks of the Sustainable Development Goals connected to Agriculture, Safety and nutritional quality of food is to raise crop production per unit area without compromising the sustainability of agricultural resources and environmental security. Along with environmental constraints, soil salinization has become one of the major threats that restricts agricultural potential and is closely related to mishandling of agricultural resources and overexploitation of water resources, particularly in arid regions. The effect of salinity on the quality of various agricultural crops has not yet been much explored. Presently, this information is very important due to the increasing use of saline water for irrigation worldwide which has given rise to as soil salinity has become a critical around the world and the situation has been worsening over the last 20 years in arid and semi-arid regions particularly in Mediterranean area. Salinity stress significantly affect the nutritional properties and quality traits of crops due to physiological and biochemical alterations in plants at different growth stage. During salinity stress, plants tend to activate different physiological and biochemical mechanisms to cope with the stress through

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_20

altering their morphology, anatomy, water relations, photosynthesis, protein synthesis, primary and secondary metabolism and biochemical adaptations such as the antioxidative metabolism response. Therefore, it is important for breeders and producers to understand the influence of salinity on the composition of crops, for improvement of protein and oil quality (amino and fatty acid) under the salinity conditions. The aims of present review is to quantify the adverse effects of salinity on quality parameters of crops and management approaches for ameliorating the adverse effects of salinity stress to enhance the yield and grain quality of crops.

Keywords Climate Change · salinity stress · Yield · Starch · oil and protein content · Crops

Abbreviations

ABA	abscisic acid
ADF	acid detergent fiber
AGC	ascorbate-glutathione cycle
APX	ascorbate peroxidase
CAT	catalase
DHAR	dehydroascorbate reductase
ET	ethylene
GB	glycine betaine
JA	jasmonic acid
MDA	Malondialdehyde
MDHAR	monodehydroascorbate dehydrogenase
MUFA	monounsaturated fatty acids
NDF	Neutral detergent fiber
POX	peroxidase

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Pro	proline
PUFA	polyunsaturated fatty acids
ROS	reactive oxygen species
SA	salicylic acid
SOD	superoxide dismutase
TFA	total fatty acids
Tre	trehalose

20.1 Introduction

Surface temperatures in mid-latitude areas will rise by 1–3.5 °C in the next 100 years due to rising atmospheric CO_2 according to the climate change models (Saxe et al. 1998; UNEP et al. 1999). Consequently, evaporation and rainfall patterns will change and drought will occur frequently so it will influence the whole ecosystems processes (IPCC 2014; UNEP et al. 1999). However, a persistent aridity expansion has been documented since the middle of the twentieth century, and this expansion will continue according to the current projection models (Dai et al. 2011). In numerous areas where a reduction is projected in the performance of crop, several developments have to be done in plant breeding programmes and agricultural technology. So knowing the alteration and reaction of salinity and their mechanisms is vital for the attainment of those goals.

Soil salinization, normally referring to the gathering of more water-soluble salts in the soil, negatively influences the soil performance (Daliakopoulos et al. 2016; Van Beek et al. 2012). Alongside its natural or primary form, soil salinity arises as a key threat to our environment predominantly in the areas of arid and semi-arid that will impede the soil performance, agricultural sustainability, and also food safety (Wallender and Tanji 2011; Suarez 2001). Presently, at least 100 countries mainly Pakistan, China, United States, India, Argentina, Sudan, and also several countries in Central and Western Asia (Aquastat, 2016), in addition to the Mediterranean coastline (Daliakopoulos et al. 2016) are facing the problem of salinity (Qadir et al. 2006), in total occupying 932.2 Mha (Rengasamy 2006). Globally both food and forages production have impeded by the processes of salinization. Qadir et al. (2006) measured the annual losses in the agricultural sector as 27.3 million US dollars caused by the salinized lands. Bridges and Oldeman (1999) determine that, secondary salinization converts 3 ha of arable land to unproductive in every minute at a global scale, consequently converting irrigated land in the range of 10–20 million hectares to zero productivity in each year. So, salinity is consider one of the main hurdler in the way of increasing food production in order to meet the demand of the mounting world population, now predictable to cross 9 billion mark by 2050 (Shabala and Munns 2017).

The population in the world is growing rapidly which necessitates producing 87% more food particularly staple crops such as rice, wheat, and maize by 2050 (Kromdijk and Long 2016). At the same time, climatic change impacts has already fingered, due to greater vulnerabilities and less ability of crop cultivars to survive against the abiotic stresses (Ali et al. 2017; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017a, b; Habib et al. 2017; Hafiz et al. 2016; Hafiz et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, Saud et al. 2016, 2017; Shah et al. 2013; Qamar-ur et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017), through changing the growth, physiology and metabolism of plants (Lunde et al. 2007; Islam et al. 2011; Islam 2012; EL Sabagh et al. 2015b; Al-Ashkar et al. 2016; Molla et al. 2019; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Major abiotic stress, including salinity, drought, heat and cold, are unfavorably threatens for crop (Pareek et al. 2010; Mantri et al. 2012; Barutcular et al. 2016). Environmental stresses condition could hasten seed filling rate and reduced the period of grain filling (Yazdi-Samadi et al. 1977).

Among various environmental stresses, soil salinity has become a critical around the world and expected to increase due to global climate changes and as a consequence of many irrigation practices (Ahmad et al. 2012). Soil salinity is expected to be increased due to global climate changes as well as a significance impotence of many irrigation practices. Salinity is also considering one of the main climatic factors for declining the productivity and quality of crops in several developing countries (Yassin et al. 2019a, b; EL Sabagh et al. 2019a, b, c). Soil salinity affects about 800 million hectares of arable lands worldwide (Munns and Tester 2008) and the situation has been worsening over the last 20 years in arid and semi-arid regions particularly in Mediterranean area (Colla et al. 2010; Cirillo et al. 2016).

Under saline conditions, plants have to activate different physiological and biochemical mechanisms in order to cope with the stress. Such mechanisms include changes in morphology, anatomy, water relations, photosynthesis, the hormonal profile, toxic ion distribution, and biochemical adaptations such as the antioxidative metabolism response) (Ashraf and Harris 2013; Acosta-Motos et al. 2015). Salt stress affects all the major processes such as photosynthesis, protein synthesis, primary and secondary metabolism (Parida and Das 2005). For example, salinity stress during the grain-filling stage may have drastic effects on wheat yield and grain quality by hampering appropriate grain-filling (Wardlaw and Moncur 1995), accelerated cell death, and an earlier maturity (Altenbach et al. 2003), which may result in substantial changes in the protein composition of the grains and starch granules (Balla et al. 2011). The effects of salt stress on the nitrogenous compounds are fairly well known (Mansour 2000). Amino acids and polyamine accumulation in salt stress tolerant species has been studied by several investigators (Willadino et al. 1996). Salt stress resulted in an elevation of amino acid levels in plants (Fougere et al. 1991). Salt stress induced increase in the endogenous polyamine contents has been reported in various plant species (Aziz et al. 1999). Different stresses may influence polyamine metabolism in different manners and specific function under the stress condition (Zhou et al. 1995). The differences in the endogenous polyamine responses under salt stress have been reported in different plant species.

Different strategies have been investigated for the improvement against stress tolerance of crops through foliar application of various types of chemicals like plant growth regulators, osmoprotectants and inorganic nutrients which may serve as efficient, economical and shot-gun approaches (Ashraf et al. 2008; Abdelaal et al. 2017;

Gormus et al. 2017a, b; Jahan et al. 2019; Omar et al. 2019a, b). Various inorganic and organic compatible solutes that effectively take part in plant stress tolerance include proline (Pro), glycine betaine (GB), trehalose (Tre) and several others compatible solutes (Ali et al. 2013). The exogenous foliar application of proline has been employed to enhance stress tolerance in a number of crops (Athar et al. 2009).

However, information regarding the drastic influence of salinity on the quality traits of crops and their effective management approaches is scarce. The present review aims to synthesize and evaluate the adverse effects of salinity on quality parameters of crops and various management approaches for ameliorating the adverse effects of salinity stress to enhance the yield and grain quality of crops.

20.2 Effects of Salinity on Quality Traits

20.2.1 General Effects

Salt stress has been reported to cause the inhibition of seed germination (Akbari et al. 2007), seedlings establishment as well as growth, development of plants through altering the physiological and biochemical process of plants (Islam et al. 2011; Islam 2012). The inhibition of growth is the primary injury which leads to accelerate the leaf senescence and cell death may also occur under severe salinity shock. Salt stress induces the synthesis of abscisic acid which closes the stomata when transported to the guard cells. As a result of stomatal closure, rate of photosynthesis declines, and photo-inhibition as well as oxidative stress occur. An immediate effect of osmotic stress on the plant growth is the inhibition of cell expansion either directly or indirectly through the action of abscisic acid (Jouyban 2012). Total number of sterile panicles and number of unfilled panicles were significantly influenced under different saline conditions (Aref and Rad 2012).

20.2.2 Effects on Protein and Oil Content

Salinity remarkably reduced the protein and oil content of seeds of soybean (Ghassemi-Golezani et al. 2010), wheat (Francois et al. 1994; Soltani et al. 2006), rice (Zeng and Shannon 2000; Shereen et al. 2005), maize (Feng et al. 2017) and tomato (Yurtseven et al. 2005). Ghassemi-Golezani and Farhangi-Abriz (2018) found that oil and protein contents in soybean cultivars decrease with increasing salinity as a result of reduction in duration for protein and oil accumulation. Similarly, Medhat (2002) reported that the reduction in protein content under higher salinity might be due to disruption in nitrogen metabolism or restricted of nitrate uptake as a result of decline water absorption and less root permeability. Yazdi-Samadi et al. (1977) showed that salinity decreases the grain-filling duration that inhibits the protein and fat accumulation. Salinity resulted in a significant reduction of the grain protein, fat and fiber contents in soybean (Chu and Luo 1994) and in wheat (Abbas et al. 2013). Salt stress disturbed in some processes like photosynthesis, protein synthesis and lipid metabolism, which lead to deteriorate grains quality of wheat (Parida and Das 2005; Abbas et al. 2013). Grain quality of tolerant and semi-tolerant genotypes was less affected by saline stress compared to sensitive ones, like grain dimensions and amylose content in rice (Rao et al. 1993).

The significant oil content reduction in soybean cultivars was observed by EL Sabagh et al. (2015a) under salt stress, which was consistent with the result of Zadeh and Naeini (2007), who reported that the reduction of oil percentage may be attributed to the weakening of salinity to protein-pigment-lipid complex or enzyme activities. The reduction in protein content under salinity stress was also reported by EL Sabagh et al. (2015b) in soybean cultivars may also be due to the disturbance in nitrogen metabolism or inhibition of nitrate absorption. However, these results differ from those of (Francois et al. 1994) who reported that increased salinity did not affect significantly the oil or protein content of the off-free seed meal.

20.2.3 Effects on Fatty Acids

Fatty acid composition is the most important quality characteristic in oil quality of oilseed crops. Suitability of a vegetable oil for nutritional, industrial or pharmaceutical applications is determined by its fatty acid composition, which is highly inconsistent depending on the plant species or variety (Yeilaghi et al. 2012) and prevalent environmental conditions (Primomo et al. 2002). It is reported that fatty acid content in oil seed crops decreased with increasing salinity. The reduction in total fatty acid content by the salt stress was attributed to a new pattern of resource partitioning providing more carbon skeletons for terpene biosynthesis and accumulation (Bybordi et al. 2010). The polyunsaturated fatty acids decreased, while the monounsaturated ones increased in response to increasing salinity levels (Bybordi et al. 2010).

Changes in the ratio of fatty acid synthesis and a reduction in the concentrations of triacylglycerols containing primarily unsaturated fatty acids has been reported in cotton seed oil under salt stress (Smaoui 2000). There is evidence that unsaturated fatty acids in membrane lipids could protect the photosynthetic machinery against salt stress (Allakhverdiev et al. 2001). The latter study reported that fatty acid composition of high-linoleate oil was not affected by increasing salinity, while fatty acid composition was altered in the high-oleate cultivars, resulting in depressed oleic acid contents (Irving et al. 1988). However, salinity had no significant effects on percentages of saturated fatty acids of palmitic acid and stearic acid, but enhanced oleic acid and reduced linoleic acid, linolenic acid percentages as unsaturated fatty acids. All the major plant processes such as photosynthesis, protein synthesis, energy, lipid metabolism and hormonal balance are affected by salt stress (Parida and Das 2005).

Salinity stress can alter fatty acid composition of soybean seeds (Primomo et al. 2002), reducing the total fatty acids. Moreover, the percentages of linoleic (C18:2) and linolenic (C18:3) acids decreased, while the oleic acid (C18:1) increased as a result of increasing salinity (Bybordi et al. 2010). Similar changes were reported in fatty acid composition of safflower under salinity stress (Yeilaghi et al. 2012). Oleic acid synthesis with formation of 18:1 happens in plastids, while desaturation to 18:2 and 18:3 occurred in the cytosol, and salinity limits this transport, leading to an increase in percentage of oleic acid, and a decrease in percentages of linoleic and linolenic acids (Flagella et al. 2004). Since two latter fatty acids are produced from the former fatty acid.

Increasing the concentrations of NaCl, reduced the plant growth and subsequent gradual decrease in total fatty acids (TFA) content. Moreover, a reduction in polyunsaturated fatty acids (PUFA) in favour of monounsaturated fatty acids (MUFA) was noted by Bybordi (2010), could be due to a result of a new pattern of resource partitioning providing more carbon skeletons for terpene biosynthesis and accumulation. Increasing soil salinity levels strongly influences the essential oil biosynthesis (Solinas and Deiana 1996).

20.2.4 Effects on Amino Acids

Salinity affects plant metabolism, including lipid metabolism in many plants (Erdei et al. 1980). In several cases, a change in lipid composition in response to salinity was correlated with adaptive properties of the species involved (Anwar et al. 2006). Wolf et al. (1982) reported that the synthesis of protein and its building blocks (amino acids) decreased as the salinity level was increased. Karr-Lilienthal et al. (2005) reported that amino acid contents in soybean seeds were lower in cooler zones in comparison to warmer zones. Decreasing protein percentage and protein content with increasing salinity could be associated with the disturbance in nitrogen metabolism and inhibition of nitrate absorption (Farhangi-Abriz and Ghassemi-Golezani 2016). However, salinity has a negative impact on synthesis of leucine and valine.

Amino acids and polyamines are related in their metabolic pathways and these are affected by salinity through alteration in enzymatic levels (Slocum and Weinstein 1990). Where, the level of amino acids increased and putrescine (PUT) content decreased and via versa (El–Bassiouny and Bekheta 2005). Similar results were reported by Aziz et al. (1999) where NaCl decreased the PA level and increased proline content in tomato leaves. Amino acid accumulation (e.g. arginine and proline) may be considered as a detoxification mechanism of the ammonium produced in plants subjected to stress (Slocum and Weinstein 1990). Among the accumulated amino acids, proline may be of special interest because of its proposed role in plant salt tolerance (Mansour 2000).

Grains of rice grown in saline soils have higher brown rice protein (higher nutritional value), less translucent grain, lower starch and amylose contents than their control samples, although alkali spreading value and gel consistency are not affected by culture in saline soils (Siscar-Lee et al. 1990). Salt tolerant indigenous rice varieties have potential consumers preferences and they could be used for breeding programme for the improvement of valuable grain quality traits such as amylose content, gelatinization temperature and grain shape, which influence the physicochemical properties like texture (Bhonsle and Krishnan 2011). In contrary, Borrelli et al. (2011) observed the positive effect of salinity stress on the protein content of durum wheat genotypes. Katerji et al. (2005) also reported that the protein contents of durum wheat genotypes were not significantly influenced by salinity stress. Although grain protein composition depends primarily on the genotype but it is significantly affected by environment factors and their interactions (Zhu and Khan 2001). Another aspect of milling-quality of importance to millers is test weight, which is highly affected by environmental stress (Salehi and Arzani 2013).

Previous research in durum wheat showed differential response of salt tolerant and salt sensitive cultivars to salinity stress regarding grain quality as salt-tolerant cultivars gave better survival rate (Katerji et al. 2005). They found a positive effect of salinity on ash content and SDS sedimentation volume and a negative effect on beta carotene content in grain was observed by Katerji et al. (2005). On the other hand, Francois et al. (1986) observed a reduction in ash content and protein quality due to salinity by visualizing bread loaf volume with enhanced colour and protein content. The wheat flour quality and grain yield are strongly associated with the genetic factors as well as environmental conditions which considerably affect their expression during grain filling (Souza et al. 2004). In fact, salinity stress as the major environmental variable influenced the rate and duration of wheat grain development and composition (Salehi and Arzani 2013). Katerji et al. (2005) observed that the gluten content of two salt sensitive and tolerant durum wheat varieties were not affected by salinity. Similarly, Darvey et al. (2000) observed a higher protein content of triticale than wheat.

20.2.5 Effects on Forage Quality

Information on forage quality of halophytes in each phenological stage could help range managers to choose suitable plant species for cultivation and also to determine suitable grazing time to achieve higher animal performance in saline rangelands (Esfahan et al. 2010). Among the forage crops, alfalfa occupies pivotal position in terms of area under cultivation due to superior characteristics such as faster growth after each cutting, high nutritional value and palatability to livestock, and also capable to grow under salinity stress. Although, under salinity, nutritional elements such as N, P, Mg, Na, Cl and S, and nutritional quality such as the net energy, crude protein and the relative feed value of forage slightly improved, but other essential nutrients such as Ca, K were decreased (Ferreira et al. 2015). From a 3 years study conducted in Ethiopia by Daba et al. (2019) revealed that biomass yield, and nutrient quality of three Rhodes grass genotypes were negatively affected due to five levels of salinity (i.e., 0, 5, 10, 15, and 20 dS m^{-1}), and also salinity stress lowered chlorophyll and crude protein content.

In arid and semi-arid regions, without irrigation forage yield remains sub-optimal, while saline soils and irrigation water in these regions causes drastic reduction in forage yield and nutritional quality of cereal and legume forages (Smedema and Shiati 2002). Although, some of the distinctive agronomic managements could help to get sufficient forage yield as well as improve the quality of forage under salinity stress (Al-Khatib et al. 1992; Mass and Grattan 1999; Ashraf and Harris 2004). Several studies noted that forage yield, nutritional values of alfalfa were significantly decreased by the salinity stress in soils and water in the Mediterranean regions (Robinson et al. 2004; Grattan et al. 2004; Suyama et al. 2007; Steppuhn et al. 2012). An investigation conducted by Farissi et al. (2014), showed that due to soils and saline irrigation water, yield reduction of alfalfa was recorded from 19.34% to 25.65%; similarly quality of forage of alfalfa (protein and nitrogen ratio) was also reduced.

Makarana et al. (2017) conducted an observation in north-western region of India and found that pearl millet forage yield and quality (Neutral detergent fiber and acid detergent fiber) were influenced significantly by the salinity severity (~0.6, 3, 6 and 9 dS/m in irrigation water). While saline tolerant genotype were not influenced by the level of salinity. Similarly, Morais Neto et al. (2012) observed that forage yield and quality of *Echinochloa pyramidalis* were influenced significantly due to the various levels of salinity (0.75, 2.0, 4.0, 6.0 and 8.0 dS m^{-1}), while the maximum level of salinity (8.0 dS m^{-1}) severely reduced the forage yield and quality such as protein, carbohydrate, NDF and ADF.

20.3 Mitigation Strategies

20.3.1 Management of Salinity Stress

During stress conditions, plants need to maintain internal water potential below that of soil and maintain turgor and water uptake for growth (Tester and Davenport 2003). This requires an increase in osmotica, either by uptake of soil solutes or by synthesis of metabolic solutes (Jouyban 2012). Cytoplasm accumulates low-molecular mass compounds, the compatible solutes to accommodate the ionic balance in the vacuoles, because they do not interfere with normal biochemical reactions (Zhifang and Loescher 2003). Currently, strategies might be adopted which could be used to get optimized quality properties under stressful environments (Mbarki et al. 2018a). Salinity might be minimized with reclamation, water and drainage, however, the cost of managing is very high.

High salinity has been reported to induce reactive oxygen species (ROS) formation and accumulation in plant cells (Chawla et al. 2013). Antioxidant enzymes activities reduced under stress condition, which imparted susceptibility in plant against salinity. So, supplementary enzymatic antioxidant mechanism including catalase (CAT), superoxide dismutase (SOD), peroxidase (POX) and enzymes of the ascorbate-glutathione cycle as ascorbate peroxydase (APX), monodehydroascorbate dehydrogenase (MDHAR), dehydroascorbate reductase (DHAR) (Foyer and Noctor 2011; Chawla et al. 2013) and non-enzymatic antioxidants as phenolics, flavonoids (Gupta and Huang 2014; Rakhmankulova et al. 2015; Talbi et al. 2015), could play a vital role to survive plant under stress condition.

Plant growth regulators such as salicylic acid (SA), jasmonic acid (JA), abscisic acid (ABA) and ethylene (ET) activate the signalling pathways to improve antioxidants activity to survive plant under stress conditions (Marco et al. 2015). Ascorbic acid has been used to counteract the adverse effects of salt stress in many crop plants (Beltagi 2008). It has proposed functions in whole plant metabolism (Debolt et al. 2007). All the values of foliar sprays ascorbic acids significantly increased quality traits as compared to untreated plants (without foliar spray) under all the soil salinity level in wheat (Desoky and Merwad 2015).

Salicylic acid (SA) might be mitigate the harmful effects of salinity by enhancing the activities of antioxidative enzymes (Idrees et al. 2010, 2011). The foliar spray with SA at different rates under the saline level gave significant improved protein content (Desoky and Merwad 2015). The SA plays a significant role in development and defense performances under stress environment of crops (Cameron 2000). Furthermore, SA overcame the unfavorable effects of salinity stress to oil content (Idrees et al. 2011) and also improved the essential oil content (Rowshan et al. 2010). Foliar application of SA remarkably improved seed yield, oil content per seed, and oil yield per plant of soybean (Ghassemi-Golezani and Farhangi-Abriz 2018). Exogenous application of SA enhances the plant growth and photosynthetic capacity under saline conditions (Khan et al. 2014). It has been also reported that SA significantly reduces ion leakage and toxic ion accumulation (Hayat et al. 2010a, b), thereby mitigating some of the deleterious effects of environmental stresses (Shakirova et al. 2003). Khodary (2004) found that SA could induce salt tolerance in maize plants via accelerating their photosynthetic performance and carbohydrate metabolism. Increasing seed and protein yields with SA treatment in soybean seeds (Farhangi-Abriz and Ghassemi-Golezani2016) may be related with increasing activities of many anti-oxidant enzymes (Shi et al. 2006), decreasing synthesis of ethylene (Leslie and Romani 1986), improving nitrogen and sulfur uptakes and enhancing maximum efficiency of PSII (Ghassemi-Golezani et al. 2015).

Jasmonic acid (JA) enhances synthesis of linoleic and linolenic acids production from oleic acid via increasing the activity of lipoxygenase (Schaller et al. 2004), while JA treatment enhanced seed oil percentage without altering seed and oil yields. Application of SA and JA improved oil quality of soybean seeds by reducing oleic acid and enhancing linoleic acid, linolenic acid contents and UI (Ghassemi-Golezani and Farhangi-Abriz 2018). Qiu et al. (2014) reported that JA application significantly relieved the adverse effects of NaCl stress. Foliar application of JA on soybean plants improves nitrogen and sulfur absorptions and also plant performance under salt stress (Farhangi-Abriz and Ghassemi-Golezani 2016). Kang et al. (2005) found that the uptake of sodium decreases, but the uptake of the major ions partially increases as a result of foliar spray of JA on rice seedlings. Foliar application of JA on soybean under salt stress reduced the damaging influence of salt and improved photosynthesis and yield (Yoon et al. 2009). Foliar application of JA enhanced the phenylalanine and tyrosine (aromatic amino acids) contents in seeds via stimulating shikimate pathway (Tzin and Galili 2010; Farhangi-Abriz and Ghassemi-Golezani 2016).

Citric acid (CA) is an organic compound belongs to carboxylic acids group. Citric acid is considered as one of non-enzymatic antioxidants which acts to eliminate free radicals produced in *Leymus chinensis* plants (Yan-Lin and Soon 2001); in *Setaria italica* and *Panicum miliaceum* (Islam 2012) under saline and alkaline stresses. Citric acid also induced defense mechanisms by increasing the activities of antioxidant enzymes (Sun and Hong 2011). Moreover, CA stimulated growth parameters, endogenous growth hormones, carbohydrate constituents and grain yield of wheat under normal and salinity conditions (Sadak et al. 2013).

Proline (Pro) induces the expression of salt-stress-responsive proteins and enhances the adaptability of crop to salt-stress (Islam 2012). Pro application could be enhanced salt tolerance in olive tree by regulating some anti-oxidative enzyme activities and thus maintained better plant status in saline condition (Ben Ahmed et al. 2010). Humic acid promotes quality in a number of plant species (Yildirim 2007). The optimum oil yield was obtained by humic acid combined with foliar of Pro under salinity stress in flax (Bakry et al. 2014). Exogenous Pro or organic manure confers tolerance to salinity by increasing K^+/Na^+ ratio and nutrient uptake (Dhar et al. 2016). The role of organic compounds like Pro and organic manures in the mitigation of salt stress in plants is yet to be elucidated. Generally, exogenous amino acids treatments might mitigate the bad effects of salinity exerted on saccharides, nitrogen metabolism and mineral, which accordingly enhance the plant development (El-Samad et al. 2011).

Another approach to minimize the harmful effect of salinity is the use of foliar feeding of nutrients for increasing plant salinity tolerance by alleviating Na^+ and Cl^- injury to plants (El-Fouly et al. 2000). Supplementary K^+ can reduce the adverse effects of increasing salinity (Kavitha et al. 2012). Soybean positively responds to potassium application in regulation of oil and protein contents in seeds under salt stress (Tiwari et al. 2002).

20.3.2 Improving Salt Tolerance of Cereal Crops

An analytical comparison of improving salinity tolerance of plants through conventional breeding and genetic engineering revealed that a few salt-tolerant cultivars/lines of some potential crops are available through conventional breeding (Mbarki et al. 2018b) but not enough due to a number of reasons. A great quantity of transgenic lines with increased salt tolerance of cereal crops are known from the literature but up to now only a very few of them field-tested with sophisticated protocols (Ashraf and Akram 2009). Barley is an excellent model for the prediction of crop response to climate change, especially salt tolerance (Jamshidi and Javanmard 2018). From barley an HVA1 gene can be expressed under rice variety and can increase salt tolerance (Rohila et al. 2002). It was found that expression of HVP1 is coordinated with that of HvNHX1 in barley roots in response to salt and osmotic stresses (Fukuda et al. 2004). The main novel data regarding conventional breeding and genetic engineering for cereals shown in Table 20.1

Table 20.1 Plant growth promoting in cereal plants to survive under salinity stress

Cereal Crop	Growth improved	Parameter improved	References
Biotic Conventional Breeding			
Wheat	Genotypes LU26S and SARC-1 is able to grow in high salt levels		Munns et al. (2006)
Rice	Rice genotype CSR 10 is able to grow in high salt levels		Singh et al. (2004); Sankar et al. (2011)
Rice	Rice genotypes CSR 13, CSR 27, Narendra Usar 2, Narendra Usar 3, Basmati CSR 30 are able to grow under moderate salt stress		Singh et al. (2004); Sankar et al. (2011)
Sorghum	Hybrids are able to grow in saline area		Sankar et al. (2011)
Transgenic/genetic engineering approach			
Vacuolar Na+/H+ antiporter gene AtNHX1 engineered			
Wheat	Increase in shoot dry weight was 68% and root dry weight 26%	Germination rate, plant biomass and yield. Low leaf Na+ and high leaf K+	Xue et al. (2004)
Rice	Seedling survival increased from 51% or 81–100%	Activity of these antiporters was eightfold high	Ohta et al. (2002)
Maize	Germination capacity of transgenic plants was 80% while those of wild type 13–57% at 0.5% NaCl	Germination percentage	Xiao-Yan et al. (2004)
Common buckwheat	Able to grow, flower and accumulate more rutin in the presence of 200 mmol/l sodium chloride	Influence rutin (flavonoids) metabolism	Chen et al. (2008)
Vacuolar Na+/H+ antiporter gene PgNHX1 engineered			
Rice	About 81% higher shoot and root lengths	Well developed root system	Verma et al. (2007)
Vacuolar Na+/H+ antiporter gene OsNHX1 engineered			
Rice	Tolerate salinity level up to 0.2 M where wild plants died	High accumulation of Na+ and low K+	Fukuda et al. (2004)
Maize	Showed higher biomass and yield even at 200 mM NaCl	Yield was improved	Chen et al. (2007)
Na+/H+ antiporter SOD2 engineered			
Rice	Transgenic plants showed good performance under saline conditions	Transgenic plants accumulated higher K+, Ca2+, Mg2+ and lower Na+ in their shoots as compared to respective non-transformed controls	Zhao et al. (2005)

20.3.3 Role of Nano-technology in Improving Quality

Nano-technology explores wide area and opens large scope for diverse applications in fields of biotechnology and agricultural sector and the potential benefits of nano-technology could be exploited to impart salinity tolerance in economically important field crops. Nano-particles can be synthesized from metal or metal oxide through diversified approaches including physical, chemical and biological strategies. However, realizing the potential benefits of green synthesis of nano-particles over other approaches, there is a constant emphasis in this area. Nano-particles tend to show up some peculiar properties different and unique from their bulk counterpart because of their extreme small size, and open new avenues in agriculture sector. Several metal or metal oxide based nano-particles are being studied to assess their potential in plant growth and development, protection from biotic and abiotic stresses, production and role in modulating the various processes in plants. However, there is still a long way to develop the technology to achieve sustainable agriculture (Saxena et al. 2016).

Silicon nano-particle (SNP) has been reported to be an important evolution to cope with abiotic stresses. Silicon (Si) is most abundantly present in the soil and Earth's crust. Its role in plant defense and plant growth and development is most recognized and well documented. There are several studies which recognized its immense potential to mitigate effectively diverse abiotic stresses i.e. drought, salinity, cold stress and other heavy metal toxicities. However, there is a scanty of information available on exact mechanisms of Si-mediated mitigation of abiotic stresses in plants (Liang et al. 2007; Ma 2004; Datnoff et al. 2007). SNP can effectively spread in wide area. It was estimated that 1.0 gram of SNP having size of 7.0 nm diameter exhibit wide absorption surface equal to 400 m^2. Furthermore, silica nanoparticles also exhibits its effect on xylum humidity, water translocation and enhance turgor pressure, thus leaf relative water content and water use efficiency will be increased in pants (Wang and Naser 1994; Rawson et al. 1998). Si particles can also mediate several other important key effects in higher plants leading to enhance abiotic stress tolerance i.e., enhancement of antioxidant enzyme activation, enhanced uptake process, co-precipitation of toxic metal ions, immobilization of toxic metal ions in growth media and compartmentation of metal ions within plants. All such processes, increase plant capabilities to withstand abiotic stresses including salinity, drought, heavy metal toxicity etc. (Liang et al. 2007).

The impact of nano-particles (SiO_2) further studied in tomato and squash under salinity stress, it is suggested that application of SiO_2 enhances seed germination and the antioxidant system under salinity stress (Haghighi and Pourkhaloee 2013; Siddiqui et al. 2014). Although usages of nano-particles in different applications is increasing widely, but still very less information is available on actual consequences of plant interaction with nonmaterial.

A study revealed that TiO2 nano-particles (rutile phase) enhanced antioxidant stress tolerance by modulating various processes like lowering of superoxide radicals accumulation, hydrogen peroxide, malonyldialdehyde (MDA) content, and inducing antioxidant enzymes activities within the plants i.e. superoxide dismutase, catalase, ascorbate peroxidase, and guaiacol peroxidase on the photochemical reaction of chloroplasts of *Spinacia oleracea* (Lei et al. 2008). There are several studies which indicated that nanoparticles mediated effect on plants growth and development is concentration dependent. Nano-particles are involved in regulating the activities of antioxidant enzymes like, SOD, CAT and POD which assist plant to cope with abiotic stresses such as drought and salinity (Laware and Shilpa 2014).

Application of SNP on lentil (*Lens culinaris* Medik.) genotypes under salinity stress revealed significant increase in seed germination and seedling growth, whereas significant reduction in germination percent and seedling growth due to the salinity stress under without treatment of nano-particles. Adding SiO_2 nano-particles not only enhance seed germination and early seedling growth but also increase other related traits in lentil genotypes under salinity stress. Therefore, SiO_2 nano-particles strengthen different defense mechanisms of plants against salt toxicity (Sabaghnia and Janmohammad 2015). Stress mitigation effects of nano-silicon particle were also studied in tomato seeds and seedlings under salt stress. The results suggested that they reduced salt toxicity growth hampering impact on seed germination; root length and plant dry weight in basil (*Ocimum basilicum*), exposed under salinity stress (Haghighi et al. 2012). Salinity stress reduces the crop growth and yield because of the Na^+ ion toxicity and nano-particles (nanoSiO_2) have suggested to decrease the ionic toxicity leading to enhance crop growth and yield, thus helps crop improvement under adverse conditions (Savvasd et al. 2009). Other studies in maize suggested that nano SiO_2 increases soot fresh weight under salinity stress (Gao et al. 2006). One strategy which silica nano-particles adopts to mitigate salinity stress in plants is to reduce Na^+ ion concentration, perhaps by reducing Na^+ ion absorption by plant tissues. Since primary impact of salinity stress on plant growth is due to reduction of osmotic potential and toxicity of Na^+ ion. Silica nano-particles may help to improve plant growth under salinity stress following Na^+ ion toxicity (Raven 1982).

The current situation in nano-technology, there is a great potential benefit but an equally high uncertainty in associated risks. There are evidences for both optimism and pessimism. Pessimism is because of the huge discrepancy between the scale of research being performed on the invention of materials such as nano-particles and their associated risks. Optimism is because of the uniquely forward-looking attitude of policy makers and regulators. The unusual properties of nano-particles may result in substantially different environmental fate and behaviors than their bulk counterparts but very few observations were made in higher plant growth and yield. Because of nano-particles are spherical or faceted metal particles typically, <100 nm in size. These nano-particles are having high surface area (30–50 m^2/g), high activity, better catalytic surface, rapid chemical reaction, rapidly dispersible and adsorb abundant water. So nano-fertilizers may increase the efficiency of nutrient uptake, enhance yield and nutrient content in the edible parts and also minimize its accumulation in the soil (Raddy 2014).

20.3.4 Plant Growth Promoting Bacteria as a Natural Biotechnological Tool Under Salinity Stress

Although, various comprehensive adaptations and mitigation strategies are suggested by earlier findings to reduce the drastic impacts of soil salinity for sustainable crops production (Shrivastava and Kumar 2014). Conversely, those mitigation approaches are time consuming, expensive and sometimes not environmentally sound. Therefore, it is a burning issue for development of simple and low cost technologies to overcome salinity stress in crop field. Naturally, a wide range of soil microorganisms are associated either being in external and internal association with plants and influence their growth and development to survive under adverse conditions through mutualistic relationship (Abdel Latef and Miransari 2014). Some microorganisms, particularly beneficial bacteria and fungi can improve plant performance under stress environments and, consequently, enhance yield (Evelin et al. 2009; Compant et al. 2010). Therefore, use of these biological approaches such as using various microorganism may be used a resource conservation biotechnological approaches for salinity management and these may be used on short term basis. These microorganisms could play a significant role in plants to survive under salinity stress through exploiting plants' distinctive properties such as signaling, synthesis of compatible solutes like enzymatic and non-enzymatic antioxidants, synthesis of growth promoting hormones, and their interaction (Latef and Chaoxing 2014). In rhizosphere of plants, various microorganism particularly beneficial bacteria and fungi naturally are colonized with plants through symbiosis process (Gray and Smith 2005), those endo-cellular and intra-cellular microorganisms help to survive the plants under stress conditions, and subsequently, improve the yield of the crops (Dimkpa et al. 2009; Hayat et al. 2010a, b). Crops under soil salinization, generally, suffer osmotic stress, nutritional unavailability and toxicities, ultimately lead to decrease the crop yield (Shrivastava and Kumar 2014). The present section of the chapter focuses on the enhancement of productivity under stressed conditions and increased resistance of plants against salinity stress by application of plant growth promoting microorganisms. A details description of the microorganisms activities those lead to plants to survive under salt stress are described as following sub-heading:

20.3.5 Arbuscular Mycorrhizal as Plant Growth Promoting Fungi Against Salinity Stress

Similar to plant growth promoting bacteria, several fungi such as arbuscular mycorrhizal fungi (AMF) plays a vital role in improving plant tolerance to salt stress while serving as bio-fertilizers. The most prevalent plant symbiosis is found in 80% of vascular plant families with AMF (Schüßler et al. 2001), including halophytes, hydrophytes and xerophytes (Latef and Chaoxing 2011; Milošević et al. 2012). In this context, biological processes such as mycorrhizal application to alleviate salt stress may serve as an effective and biologically viable option. AMF have been shown to promote plant growth and salinity tolerance by many researchers (Balestrini et al. 2017; Table 20.2).

AMF colonize plant root system and improve the survival ability of plant against salt stress through improving nutrients and water uptake capacity of plants, and also improve the signalling pathway for accumulation of enzymatic antioxidant mechanism such as CAT, SOD, POX and enzymes of the AGC as APX, MDHAR, DHAR and non-enzymatic antioxidants as phenolics, flavonoids, which could play a vital role to survive plant under stress condition (Abdel Latef and Miransari 2014; Table 20.3). Similarly, activate the plant growth regulators such as SA, JA, ABA and ET which play an important role for influence the signalling pathways for synthesize of antioxidants activity to survive plant under stress conditions (Abdel Latef and Miransari 2014).

AMF penetrates the cortical cells of the roots of a vascular plant as a root obligate biotrophs which results in exchange of mutual benefits in the form of water, nutrients, and pathogen protection, in exchange for photosynthetic products with

Table 20.2 Plant growth promoting bacteria help plants to survive under salinity stress through symbiosis process.

Growth promoting bacteria	Crop species	Positive effect on plants	References
Pseudomonas pseudoalcaligenes, *Bacillus pumilus*	Rice (*Oryza sativa*)	Increased concentration of glycine betaine (compatible solute)	Jha et al. (2011)
Pseudomonas putida, *Enterobacter cloacae*, *Serratia ficaria, and Pseudomonas*fluorescens	Wheat (*Triticum aestivum*)	Enhanced germination percentage, germination rate, and index and improved the nutrient status of the wheat plants	Nadeem et al. (2013)
Rhizobium, *Pseudomonas*	Maize (*Zea mays*)	Decreased electrolyte leakage and, increase in proline production, maintenance of relative water content of leaves, and selective uptake of K ion	Bano and Fatima (2009)
Acinetobacter spp. and Pseudomonas sp.	Barley and oats	Production of ACC deaminase and IAA	Chang et al. (2014)
Rhizobium and Pseudomonas	Mung bean (*Vigna radiata*L.)	IAA production and ACC deaminase activity	Ahmad et al. (2013)
Pseudomonas fluorescens	Groundnut (*Arachis hypogea*)	Enhanced ACC deaminase activity	Saravanakumar and Samiyappan (2007)
Achromobacter piechaudii	Tomato (*Lycopersicon esculentum*)	Reduced levels of ethylene and improved plant growth	Mayak et al. (2004)

Table 20.3 AM fungus as natural biotechnological resources for sustainable crop production under salt-stress

Levels of Salinity	Crop species	AM fungus	Plant organ	Non-enzymatic antioxidants		Enzymatic antioxidants						References
				AsA	GSH	CAT	APX	SOD	POX	MDA	GR	
4.7,9.4 dSm^{-1}	*Triticum aestivum*	Mixture of *Glomus* spp.	Leaves	+	+	+		+	+		+	Talaat and Shawky (2014a, b)
0–100 μmol m^{-2} S^{-1}	*Zea mays*	*Rhizophagus irrularis, Claroideoglomus etunicatum, Septoglomus constrictum*	Shoot			+		+				Estrada et al. (2013)
0–1.0% NaCl	*Lycopersicon esculentum*	*Funneliformis mosseae*	Root			+	+	+	+	+		He et al. (2007)
2.2–12 dSm^{-1}	*Lycopersicon esculentum*	*Funneliformis mosseae*	Leaves			+	+	+	+	+		Abdel Latef and Chaoxing (2014)
0–100 mM NaCl	*Capsicum annum*	*Funneliformis mosseae*	Shoot Root					+ +	+ +	− −		Abdel Latef and Chaoxing (2014)

Non-enzymatic antioxidants: *AsA* ascorbate, *GSH* glutathione. Enzymatic antioxidants: *CAT* catalase, *APX* ascorbate peroxidase, *SOD* superoxide dismutase, *POX* peroxidase, *MDA* malnoaldehyde, *GR* glutathione reductase. **+**, increase; **−**, decrease

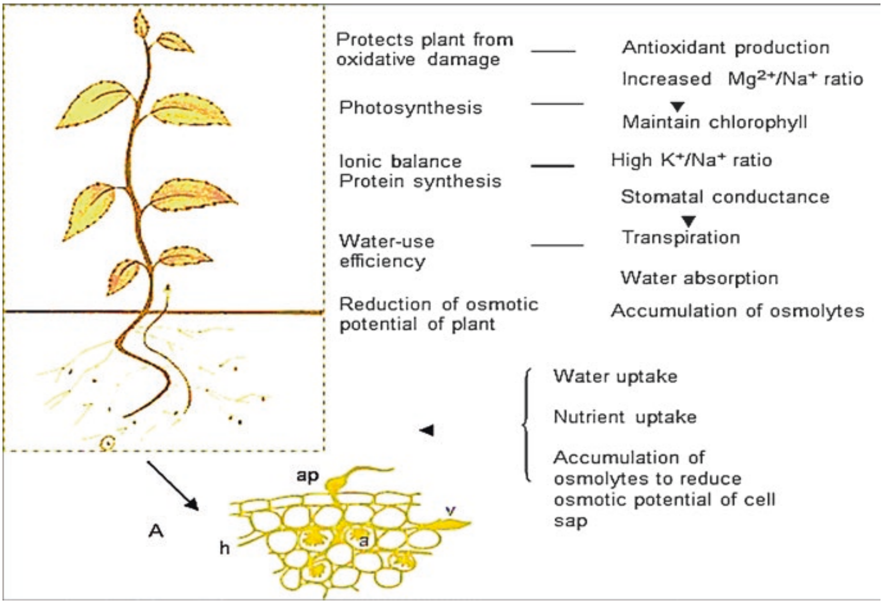

Fig. 20.1 Mechanisms through which arbuscular mycorrhizal (AMF) ameliorate the adverse effect of salinity stress on plants. (Adapted from Evelin et al. 2009)

several agricultural crops (Schüßler et al. 2001; Talaat and Shawky 2014a, b). Although the response of crops to salinity varies with species, plant metabolism is affected resulting in reduced plant growth and yield; however during symbiosis of AMF, the fungus forms an appressorium (ap) on the root surface and enters the root cortex by extending its hyphae (h). The hyphae form arbuscules (a) and vesicles (v) in the cortex (Evelin et al. 2009; Fig. 20.1).

20.4 Conclusions

Salinity stresses drastically influenced the vegetative and reproductive growth, yield, and quality traits of field crops. However, reproductive stage of crops has been observed to be the most critical stage which is influenced by abiotic stresses especially salinity. To overcome the negative effects of salinity stress, several strategies have been developed by researchers which have partly served the purpose. Nonetheless, in recent decades, exogenous application of antioxidants has been found to improve crops yield and quality under salinity stress. There is a dire need to evaluate and devise new strategies to cope salinity which is feared to become even more drastic under changing climate.

Financial Support This is a collaborative work. No financial support was assisted for the chapter.

Conflict of Interest Authors declared no conflict of interest

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Chapter 21
Advances in Pyrolytic Technologies with Improved Carbon Capture and Storage to Combat Climate Change

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Abstract Emission of greenhouse gases (GHG) including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) due to anthropogenic activities has changed the world climate, consequently resulting in global warming. Biochar can potentially deplete atmospheric carbon (C) levels and enhance C sequestration to combat climate change. Lower mineralization and higher recalcitrance of biochar enhance the C sequestration and reduce the release of CO_2. Biochar application to the soil reduces N_2O and CH_4 emissions and increase microbial growth and activities. The recalcitrance and C sequestration potential of different biochars were investigated by using recalcitrance index (R_{50}), H/C and O/C molar ratios, and proximate analyses in this chapter. Biochar+silica composite pyrolyzed at 600 °C (BC+S600), ball-milled biochar+silica composite pyrolyzed at 600 °C (MBC+S600), and eggshell+biochar composite pyrolyzed at 600 °C (EP-BC600) were highly recalcitrant, exhibiting R_{50} values above 0.7. Interestingly, BC+S600 and MBC+S600 exhibited the highest values of C sequestration potentials as well (95.59% and 21.17%, respectively). However, pyrolysis temperature, feedstock type, soil characteristics, and biochar application rates affect the efficiency of biochar for GHG mitigation, its recalcitrance, and C sequestration potential. Thus, the efficiency of biochar for C sequestration can be enhanced with advanced smokeless biomass pyrolytic techniques for safe energy production and climate change mitigation.

Keyword Greenhouse gases · Carbon sequestration · Recalcitrance · Negative emission

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_21

21.1 Climate Change: A Giant Threat to Planet Earth

Climate change is a fundamental threat to the millions of species living in the terrestrial and aquatic environment globally. Global and regional temperature shifts due to several anthropogenic activities including fossil fuel burning, carbon dioxide (CO_2) emission from vehicles, greenhouse gases (GHG) effects, industrial waste, and deforestation are disturbing the ecosystem drastically. The natural balance of GHG was disturbed after the beginning of the industrial era in1750 (IPCC 2013). In 2012, CO_2 concentration has elevated by 41% (393 ppm) in comparison to 1750 (WMO 2013). This increase in CO_2 concentration has enhanced GHG effect by trapping sunlight in the atmosphere consequently rising global climatic temperature. It has been estimated that continual emissions of GHG gases due to overconsumption and exploitation of natural resources would cause a rise in global temperature about 4–6 °C by the end of this century (Rockstrom 2010). Exceeding global warming consequences to 4 °C warmer would cause severe climate events including a rise in sea level, ocean acidification extreme heat waves and drought (World Bank 2012; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). In 2003, more than 70,000 deaths were reported in Europe due to the summer heat wave (Robine et al. 2008). Likewise, more than 60,000 causalities are reported annually as the ultimate consequences of harsh weather conditions around the globe (World Bank 2012). Moreover, temperature elevations could lead to variable rainfall patterns and melting of glaciers consequently increasing the frequency and intensity of floods. As a result, the floods contaminate fresh water resources, increase water-borne and infectious diseases and provide a breeding ground for several insects such as mosquitos. According to the World Bank (2012) report, due to contamination of freshwater resources by variable rainfall pattern and flooding, every year around 500,000 deaths are reported. On the contrary, water scarcity causes drought and famine.

Thus, climate change is one of the greatest threats mankind is facing at present. We cannot wait or escape from this problem; rather, we have to act to resolve this issue on immediate basis. Actions we take now will decide what the world would be in the coming decade or century. It needs huge and sincere efforts from all of us to work together to overcome the challenges of extreme weather, adversely changing the pattern of climate and global warming.

21.2 Biomass Pyrolysis Technology: A Tool to Convert Biomass into Long-Lived Carbon

Energy is one of the most important factors for the growth and development of a nation. The economic, industrial and technological growth of a country is largely energy dependent (El-Saeidy 2004). There is an increasing pressure of energy demand to meet the basic needs, industrialization and technical advancement of rapidly developing countries. Burning of fossil fuels is the main source to meet up the world's energy requirement. At present, 85% of the world's energy demand is being fulfilled by the combustion of fossil fuels. The global energy requirement is expected to rise by about 50% in 2025 and rapidly growing countries share the major part of it (Agbro and Ogie 2012). Therefore, energy production processes are emitting a huge amount of GHG into the atmosphere on a daily basis. Estimated release of CO_2 in energy production processes would reach to 35.6 billion metric tons in 2020 and 43.2 billion metric tons in 2040 from 32.3 billion metric tons in 2012, subsequently leading to severe global warming (Conti et al. 2016; Nes et al. 2015). Therefore, there is an urgent need to produce alternative energy sources which must be renewable and most importantly harmless and environment-friendly.

Biomass pyrolysis technology has recently come up as an alternate energy source with multiple socio-environmental benefits. Each year around 120 Gt of C is fixed by plant biomass during photosynthesis. As biomass is not a stable C material, therefore, the entire C returns back into the atmosphere after decomposition of the biomass and through the respiration. Thus, the main concept behind biomass pyrolysis is to transform unstable C into a stable form, which can stay in the soil for thousands of years (Geider et al. 2001; Sauerbeck 2001). The biomass is generally characterized as a biodegradable organic material derived from plants, animals, agriculture, industrial and municipal wastes (Basu 2010). The biomass is the only renewable source of fixed carbon (C) has gained great attention as a renewable and non-hazardous energy source specifically after the oil crises of the last decade (Bridgwater and Bridge 1991). Biomass energy generating processes are well-known carbon neutral practices, because no additional CO_2 is added to the atmosphere (Park et al. 2018). Previous studies have reported several plants, animal and agriculture-derived waste materials used as biomass including corn cobs (Mullen et al. 2010), cotton seeds hull (Uchimiya et al. 2011a), oak bar and oak wood, orange peel (Chen and Chen 2009), wheat straw, barley straw (Jahirul et al. 2012), Conocarpus tree waste (Al-Wabel et al. 2015), date palm leaflet (Al-Wabel et al. 2018), cotton straw and stalk (Putun 2002; Chen et al. 2003), rice straw and pine sawdust (Chen et al. 2003), poultry litter (Cantrell et al. 2012), manure waste (Cely et al. 2015), cow dung (Oladeji 2011) and solid municipal waste (Randolph et al. 2017). Generally, biomass comprised of cellulose, hemicellulose, lignin, sugar, fat, protein, water and some additional minor compounds (Demirbas 2001; Duku et al. 2011; Verma et al. 2012). Cellulose is the largest fraction in BM (30–50%) followed by hemicellulose (20–35%), lignin (15–20%) and 15–20% rest of compounds (Haghighi Mood et al. 2013). The plants are considered as the primary source of biomass on Earth. During photosynthesis, atmospheric CO_2 is consumed by plants which are stored as C in biomass, which can be converted in energy or transformed into fixed C through various thermos-chemical processes including combustion, gasification, liquefaction, and pyrolysis. A wide array of products including liquid fuel, fuel gas, and solid char can be obtained from biochar with the aforementioned treatments. Gasification is partial oxidation of C containing solid waste material to produce gas, generally known as syngas which consists of hydrogen (H) and CO_2 (Basu 2010), while open-air combustion of biomass releases heat and toxic substances to the atmosphere. Therefore, scientists have focused on effective utilization of biomass for production of energy and ecologically valuable products. Hence, out of the several technologies for converting biomass into valuable energy product, pyrolysis is known as the most economical technique for production of bio-oil, C rich solid char material, and biogas.

Pyrolysis is the combustion of biomass in a controlled environment (limited supply of oxygen) to produce solid (biochar, hydrochar), liquid (bio-oil, ethanol, and methanol) and gaseous fuels (hydrogen and synthetic gases) (Girard and Fallot 2006). Pyrolysis has a distinction from gasification as no oxygen is required for pyrolyzing biomass, while partial oxidation is involved in gasification (McKendry 2002). The pyrolysis of biomass results in the breakdown of its main components (cellulose, hemicellulose, and lignin) into bio-oil, solid char material and syngas in temperature range of 25–800 °C (Azargohar et al. 2013; Downie et al. 2012; Brebu et al. 2010; Fisher et al. 2002). The bio-oil produced by pyrolysis is upgraded to bio-fuels by further processing and can be used as an alternative to fossil fuels. Likewise, syngas gas can be used to produce synthetic chemicals. Recalcitrant form of C (biochar) produced by pyrolysis can also be used for long term C storage to mitigate climate change (Liu et al. 2015; Huber et al. 2006).

Pyrolysis technology is classified as slow, intermediate and fast pyrolysis, however, slow and fast pyrolysis are commonly used systems. Proportion and yield of the produced components depend on the pyrolysis conditions and feedstock type. Fast pyrolysis is carried out by rapid heating and short resident time, and it produces bio-oil of greater quality in quantity (Brownsort 2009). Slow pyrolysis is comprised of slow heating rate and long resident time and produces biochar as the main product (Brownsort 2009). Produced biochar characteristics depend on initial thermal treatment and type of the feedstock (Uchimiya et al. 2011b). Biochar produced at lower pyrolysis temperature has a higher yield, cation exchange capacity, an extra number of functional groups and lower fixed C contents, while biochar produced at higher temperature has higher pH value, higher fixed C and highly recalcitrance (Glaser et al. 2002; Novak et al. 2009a).

Application of biochar to soil induces a combination of physiochemical and biological changes in the soil which may result in decreased atmospheric GHG and long term C sequestration (Hammond et al. 2011). Being a C neutral/negative technology, biochar has a significant influence on global C balance. Biochar fits very well in the bioenergy sector as a solution for the mitigation of GHG emissions (Proll et al. 2017). Biochar production from agricultural wastes and its application to soil is a very useful practice for atmospheric C-sequestration and to store unstable C contents of biomass for a longer period of time (Sohi et al. 2010). Beside C sequestration, biochar can potentially decrease methane (CH_4) and nitrous oxide (N_2O) emission and improve soil productivity (Gaunt and Lehmann 2008). Production of biochar by pyrolysis of biomass strengthens the idea of removing atmospheric CO_2 by photosynthesis and creates a sink for C in soil with comparably high global potential. Therefore, pyrolysis of biomass is a potential technology for converting a range of plant, animal and municipal derived waste material into renewable energy sources which are profusely desirable globally.

21.3 Biochar and Climate Change Nexus

Technological development and rapid industrialization to fulfill the needs of the ever-increasing human population have escalated environmental issues worldwide. The anthropogenic activities are continuously altering the climate of the planet Earth, consequently affecting the socioeconomic systems and health of the terrestrial and aquatic life (Watson 2003). Extensive utilization of fossil-fuel, deforestation (terrestrial and mangroves), land clearing and burning, agricultural activities and intensive tillage have increased the greenhouse gas emissions, resulting in the mean global atmospheric CO_2 concentration of 380 ppm in 2005 compared with 280 ppm in the 1700s (Lee et al. 2010). The levels of atmospheric CO_2 are continuously elevating while soil C contents are decreasing subsequently resulting in climate change. Globally, about 440 Gt of atmospheric CO_2 is being captured by land-based green plants each year due to photosynthesis process, which returns back into the atmosphere after respiration and decomposition of the biomass due to its higher degradability (Lee et al. 2010). It has been reported that the emissions of greenhouse gases must be reduced to 40–70% by the mid of this century, and to zero by the end of the century (IPCC 2014). Hence, new approaches are needed to prolong the half-life of biomass and to reduce the exponentially increasing atmospheric CO_2 levels in order to limit global warming.

Among various technologies to enhance C sequestration, the pyrolytic technique has come as the most efficient and sustainable approach to convert unstable biomass into biochar for elongated C sequestration. During the pyrolysis, about 80% of the biomass converts into liquids and gases/vapors, while 20% converts into solid, black, and stable carbonaceous material called biochar (Fig. 21.1) (Bis and Gajewski 1994; Kobyłecki 2014). The biochar is composed of amorphous C, ash, and crystallites of poly-condensed aromatics (Baishali 2014; Kobyłecki 2014). Due to the condensed aromatic structure and organometallic complex formation, biochar is considered to be decomposed very slowly and can stay in the soil from a few hundred to thousands of years. Therefore, biochar can potentially serve as a temporal sink for atmospheric CO_2 (Kobyłecki 2014; Lehmann and Joseph 2009). Biochar is playing a significant role in climate change mitigation, soil environment protection by storing C, limiting greenhouse gases emissions, improving crop production, and soil remediation and conservation (Lehmann 2007a). However, the stability of the biochar depends on the composition of the feedstock, pyrolysis temperature and resident time, hence, the recalcitrance and C sequestration of the biochar can be enhanced by controlling these properties (Kobyłecki 2014; Lehmann and Joseph 2009; Liu et al. 2013; Sun et al. 2014a, b).

It has been reported that biochar may contain up to 90% of organic C depending upon its composition and pyrolysis temperature, which subsequently can potentially mitigate climate change by enhancing soil organic C pool and reducing greenhouse gas emissions (Chan and Xu 2009; Bruun et al. 2011a, b; Laird 2008). The production of biochar and its stability in soil is considered as potential mechanism to mitigate climate change by reducing the atmospheric CO_2 emissions, long term C

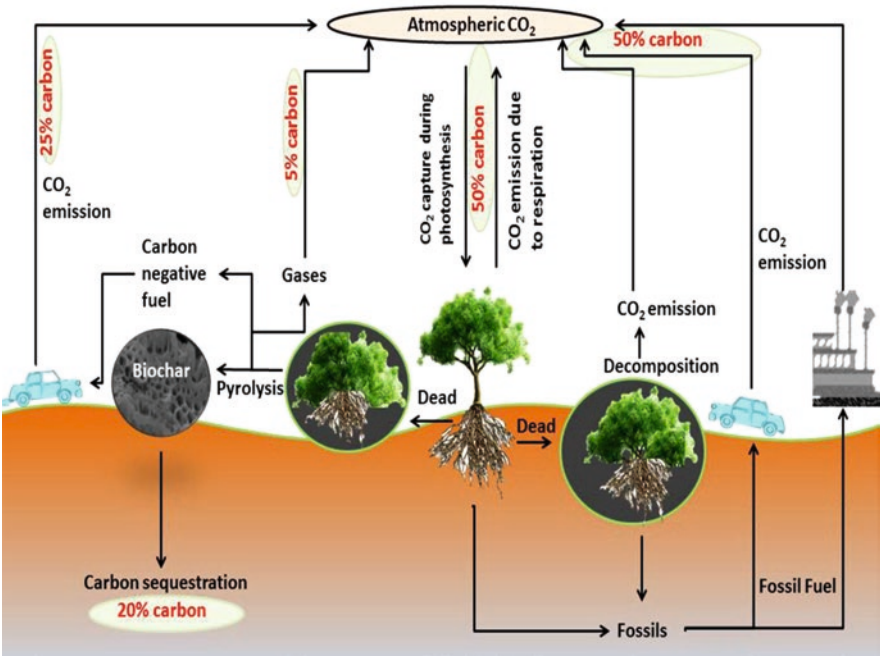

Fig. 21.1 Impacts of pyrolyzed and un-pyrolyzed biomass on the carbon cycle and carbon sequestration

storage in the soil, and switching the utilization of fossil fuel by the bio-fuel (carbon negative fuel) obtained through pyrolysis (Lehmann et al. 2006a, b; Glaser et al. 2001; Fowles 2007; Laird 2008; Lehmann 2007a; Cross and Sohi 2011). The potential of specific biochar to mitigate climate change primarily depends on its C sequestration potential which is responsible for slowing its rate of degradation/decomposition, and proximate characteristics of the biochar (Schmidt and Noack 2000; Kuzyakov et al. 2009). Therefore, it can be concluded that the C sequestration potential of particular biochar directly influences its potential to mitigate climate change.

21.3.1 Carbon Sequestration Potential of Biochars

Capturing the atmospheric C and storing into inert or stable from to avoid its emission back into the atmosphere is called C sequestration. Annual CO_2 uptake from atmosphere by green plants during photosynthesis is almost eight fold higher than the anthropogenic greenhouse gas emissions. Almost all of the captured CO_2 by the plants releases back into the atmosphere on decomposition/degradation in soil. Hence, storing even a smaller amount of C into stable forms can help mitigate climate change to larger extents. It has been observed that conversion of biomass into biochar could fix about 50% of the C within the aromatic structure of biochar, which can potentially stay in soil undecomposed for thousands of years (Fig. 21.1). Therefore, biochar is considered an ideal candidate for storing atmospheric C for thousands of years due to its thermally, physically, biologically, and chemically recalcitrant nature (Ahmad et al. 2019). The condensed aromatic composition of the biochar protects the C from releasing into the atmosphere making biochar an efficient method for C sequestration. It has been estimated that diverting 1% of annual C uptake by green plants towards biochar could alleviate 10% emissions of anthropogenic C (Lehmann and Joseph 2009). In another report, Woolf et al. (2010) stated that the storage of biochar in soil could result in the reduction of about 12% of current anthropogenic CO_2 emissions. A few other reports suggested that application of biochar could potentially limit the emission of other greenhouse gases including CH_4 and N_2O (Cayuela et al. 2014; Wu et al. 2013; Zhang et al. 2010). Lehmann et al. (2006a, b) reported that the application of biochar to the soil could sequester about 0.2 Pg C annually. Thus, application of biochar can potentially sequester more C in soil than the conventional agricultural practices which result in the release of all CO_2 back into the atmosphere (Bruun et al. 2011a, b). However, the interaction of biochar with native soil organic matter is of complex nature possessing both positive and negative priming impacts. Therefore, optimization and modification of biochar properties for the application into specific soils are of critical importance for C sequestration potential of biochar.

21.3.2 Estimation of Carbon Sequestration Potential of Biochar

The capacity of biochar for C sequestration depends on its degree of stability in the soil, which in turns is highly influenced by the type and composition of biomass and pyrolysis conditions. Depending upon the pyrolytic technique and conditions, the contents of cellulose and lignin within the biomass may degrade completely resulting in aromatic structures development. Therefore, the changes in surface, elemental and structural composition determine the stability of the biochar against decomposition by microbial, chemical and physical means. However, the estimation of the stability of biochar in different soils and climates is very complex as biochar contains both stable and degradable components based on its characteristics. The physical, chemical and structural composition of biochar, as well as, soil temperature, moisture contents, clay contents, and tillage practices provide the explanation for its degree of stability (Sohi et al. 2009). Therefore, different researchers have been trying to estimate the stability of biochar in order to predict its ability for C sequestration and subsequently climate change mitigations. The C sequestration potential of biochars is generally estimated through various chemical recalcitrance based indices, as are directly dependent on resistance to degradation (Bird et al.

2015; Spokas 2010; Harvey et al. 2012). The chemical recalcitrance is estimated by counting the unburnt precursors in feedstocks and pyrolytic conditions such as pyrolysis temperature, residence time and charring intensity (Pyle et al. 2015). Beforehand, the pyrolysis temperature was being used for the prediction of biochar stability, however, the results were found inaccurate and inconsistent (Huajun et al. 2019). Spokas (2010) reported that O/C molar ratios can also be used for the estimation of biochar stability in soil. Lehmann et al. (2006a, b) proposed that H/C_{org} molar ratio for prediction of biochar stability. However, according to the reports of the European Biochar Foundation, both O/C_{org} and H/C_{org} molar ratio are important to be considered while estimating the stability of biochar (EBC 2012). Additionally, several other methods are being developed worldwide for the estimation of biochar stability.

A few approaches for the estimation of biochar stability for C sequestration potential have been discussed below.

21.3.2.1 Biochar Recalcitrance Index (*R_{50}*)

The potential of biochar to resist chemical, physical, thermal and biological degradation/decomposition is referred to as recalcitrance potential and is considered as very crucial for the estimation of C sequestration. It has become an established fact that the stability of biochar is higher than the biomass; however, the recalcitrance of biochar after soil application is ambiguous due to various interfering factors such as the composition of biochar, soil texture, and structure, soil physical and chemical properties and environmental factors (Ahmad et al. 2019). However, real-time determination of the half-life of particular biochar is not possible. Hence, Harvey et al. (2012) introduced an index to estimate the recalcitrance potential of the biochar against thermal decomposition. As the thermal decomposition pattern of material can easily be assessed through thermogravimetric analyses (TGA-DTG), therefore, TGA curves were used to calculate the recalcitrance index (R_{50}) in comparison with the graphite which is considered as the most stable form of the carbon. Generally, the TGA curves around 30–200 °C indicate the presence of volatile organic C, 200–380 °C indicate labile organic C (cellulose and carbohydrate), 380–475 °C indicate recalcitrant organic C (lignin), 475–600 °C indicate refractory organic C (polycondensed lipids), and 600–1000 °C indicate inorganic C (carbonates) (Leng et al. 2018; Zornoza et al. 2016). Therefore, the TGA curves could effectively be used for the estimation of the thermal oxidative stability of biochars. Hence, using TGA curves, the energy required to oxidize a unit mass of graphite-C and a unit mass of biochar-C into CO_2 can be compared using R_{50}, and their C sequestration potentials can be estimated. The R_{50} can be calculated by using the following equation (Eq. 21.1) as given by Harvey et al. (2012).

$$R_{50} = \frac{T_{50,x}}{T_{50,graphite}} \tag{21.1}$$

where, $T_{50,x}$ and $T_{50,\ graphite}$ stand for the temperatures of moisture and ash corrected TGA curves at 50% weight loss by oxidation of material (biochar) and graphite, respectively.

However, to negate the effect of ash and moisture contents, the TGA curves need to be corrected by using the following equation (Eq. 21.2) (Harvey et al. 2012).

$$W_{i,cor} = 100 + \left[100 \times \left(W_{i,uncor} - W_{200,uncor}\right) / \left(W_{200,uncor} - W_{cutoff,uncor}\right)\right] \quad (21.2)$$

where, $W_{i,cor}$ and $W_{i,uncor}$ stand for corrected and uncorrected weight loss, respectively, while $W_{200,uncor}$ stands for weight loss up to 200 °C and $W_{cutoff,uncor}$ represents the temperature with no further weight loss.

We selected some of the biochars along their corresponding feedstocks to form our previous work, corrected their TGA curves to eliminate the effect of ash and water contents and calculated their R_{50} values (Fig. 21.2). The calculated R_{50} for the selected biochars and their feedstocks ranged between 0.367 and 0.763. It can be seen in Fig. 21.2 that the R_{50} for all the feedstocks were lower than the biochars. According to the criteria established by Harvey et al. (2012), materials with R_{50} values above 0.7 are highly recalcitrant, with 0.5–0.7 are minimally degradable and below 0.5 are highly degradable.

Based on this criteria, biochar + silica composite pyrolyzed at 600 °C (BC+S600), ball-milled biochar + silica composite pyrolyzed at 600 °C (MBC+S600) and eggshell + biochar composite pyrolyzed at 600 °C (EP-BC600) were found to be highly recalcitrant, while all other biochars were found in minimal degradable category. However, the biochar produced at higher pyrolysis temperature shown higher R_{50} values compared to the biochar produced from the same feedstock at lower pyrolysis temperature. Furthermore, all the feedstocks materials exhibited that the R_{50} was below 0.5 indicating as highly degradable.

Ahmad et al. (2019) reported that the higher recalcitrance potential of biochar + silica composites could be due to encapsulation and protection of biochar with the silica particle. The silica particles may alter the structural composition of biochar by developing Si–C couplings, subsequently resulting in silica encapsulated-C formation (Guo and Chen 2014; Xiao et al. 2014). The similar mechanism could also be involved in EP-BC composite, resulting in the protection of biochar with calcite particles. Therefore, this encapsulation could increase the stability of the biochar resulting in enhanced C sequestration. Hence, it can be stated that the presence of a mineral component in the biochar may develop an organo-mineral complex, where mineral can protect the biochar from thermal decomposition, and biochar can protect the mineral form dissolution. This mutual protection results in higher recalcitrance of the biochar subsequently enhancing its C sequestration potential. To testify this hypothesis, the same biochars were subjected to C sequestration potential by using the following equation (Eq. 21.3).

$$C\,sequestration\ potential(\%) = \frac{Yield(\%).C\%biochar.R_{50}}{C\%\,feedstock} \quad (21.3)$$

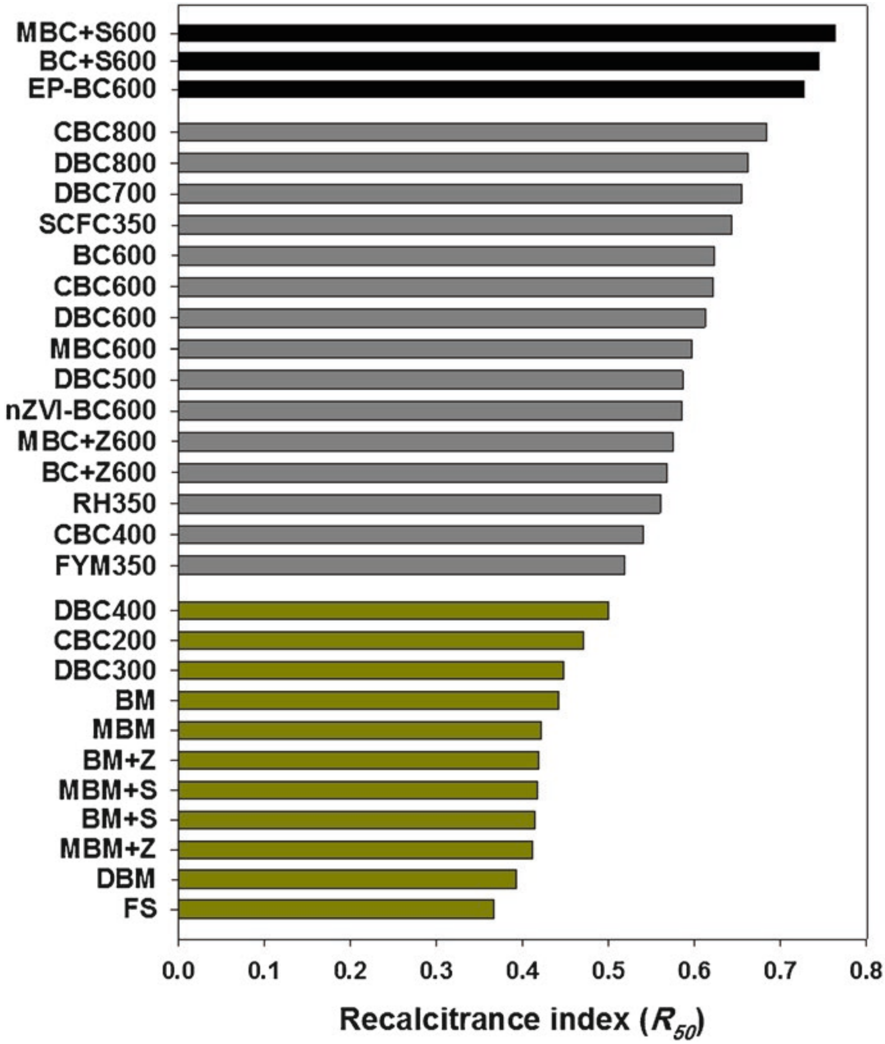

Fig. 21.2 Recalcitrance index of various feedstocks and biochar materials as calculated from Ahmad et al. (2018, 2019), Al-Wabel et al. (2013) and Usman et al. (2015). (The numeric values following the material name represent pyrolysis temperature in °C; while, DBC: date palm tree waste derived biochar; CBC: Conocarpus waste derived biochar; RH: rice husk biochar; FYM: farmyard manure biochar; nZVI-BC: nano zero valent iron composited biochar; SCFC: sugarcane filter cake biochar; BC: date palm waste biochar; MBC: milled date palm waste biochar; BC+S: date palm waste biochar composite with silica; MBC+S: milled date palm waste biochar composite with silica; BC+Z: biochar composite with zeolite; MBC+Z: milled biochar composite with zeolite; EP-BC: date palm waste biochar composite with eggshell power; BM: date palm waste biomass; MBM: milled date palm waste biomass; BM+S: date palm waste biomass composite with silica; MBM+S: milled date palm waste biomass composite with silica; BM+Z: date palm waste biomass composite with zeolite; MBM +Z: milled date palm waste biomass composite with zeolite; DBM date palm tree waste biomass; and FS: Conocarpus waste biomass)

The calculated C sequestration potentials of the selected biochars have been presented in Fig. 21.3. Interestingly, BC+S600 and MBC+S600 exhibited the highest values of C sequestration potentials (95.59% and 21.17%, respectively), confirming the results of R_{50}. The lower C sequestration potential of EP-BC600 can be referred to lower C contents in this composite. Additionally, the biochar produced at higher pyrolysis temperature shown higher C sequestration potential than the biochar produced from the same feedstock at lower pyrolysis temperature. Hence, it can be stated that the composition and the pyrolysis temperature are of significant importance to predict the stability of biochar. Moreover, organo-mineral composites pyrolyzed at higher temperatures could potentially serve as recalcitrant materials to sequester atmospheric C into the soil for an extended period of time to effectively mitigate climate change.

21.3.2.2 H/C and O/C Molar Ratios

The H/C and O/C molar ratios are considered very significant indicators for C structure assessment. It has been reported that the H/C ratios below 0.7 and O/C ratios below 0.4 represent the abundance of fused aromatic structures, which are absent in feedstock resulting is higher H/C ratios (IBI 2015). However, the presence of some inorganic carbonate may interfere with stability estimation as these are not involved in the formation of aromatic structures (IBI 2015). Therefore, H/C_{org} could provide more precise estimations as compared to H/C rations. But, a very few studies are available providing the information on H/C_{org} ratios for the estimation of biochar stability. Likewise, the lower O/C ratios indicate the more stability of the biochars and vice versa. Spokas (2010) reported that the biochar with O/C ratio less than 0.2 are the most stable and may own a half-life of more than 1000 years. The biochar with O/C ratio of 0.2–0.6 is moderately stable and possess a half-life of 100–1000 years, while biochars with O/C ratio more than 0.6 may possess a half-life of less than 100 years. Although, most of the researchers claim that both the H/C and O/C ratios are appropriate for the estimation of biochar stability. However, Budai et al. (2013) stated that the H/C is the most appropriate proxy for predicting the stability of biochar, as compared to O/C molar ratio. The reason for H/C molar ratio preference is that H can be analyzed experimentally, while the O is usually estimated by the difference method. Secondly, the O/C remains poorly distinguished in biochars with higher ash contents (Enders et al. 2012).

It has been observed that pyrolysis temperature has a significant impact on the aromaticity and hydrophobicity, subsequently on the stability of biochar. The van-Krevelen diagram was reported by Dirk van Krevelen in 1950 and plots H/C and O/C molar ratios to provide the evolution of C, O, and H during pyrolysis (van Krevelen 1950). We have collected the elemental composition data of biochar and feedstock of different origin and pyrolyzed at a different temperature from the previously published literature and produced van-Krevelen diagram (Fig. 21.4). It can be seen that the unpyrolyzed biomass exhibited the highest H/C and O/C molar ratios indicating the lowest aromaticity. The H/C and O/C ratios decreased

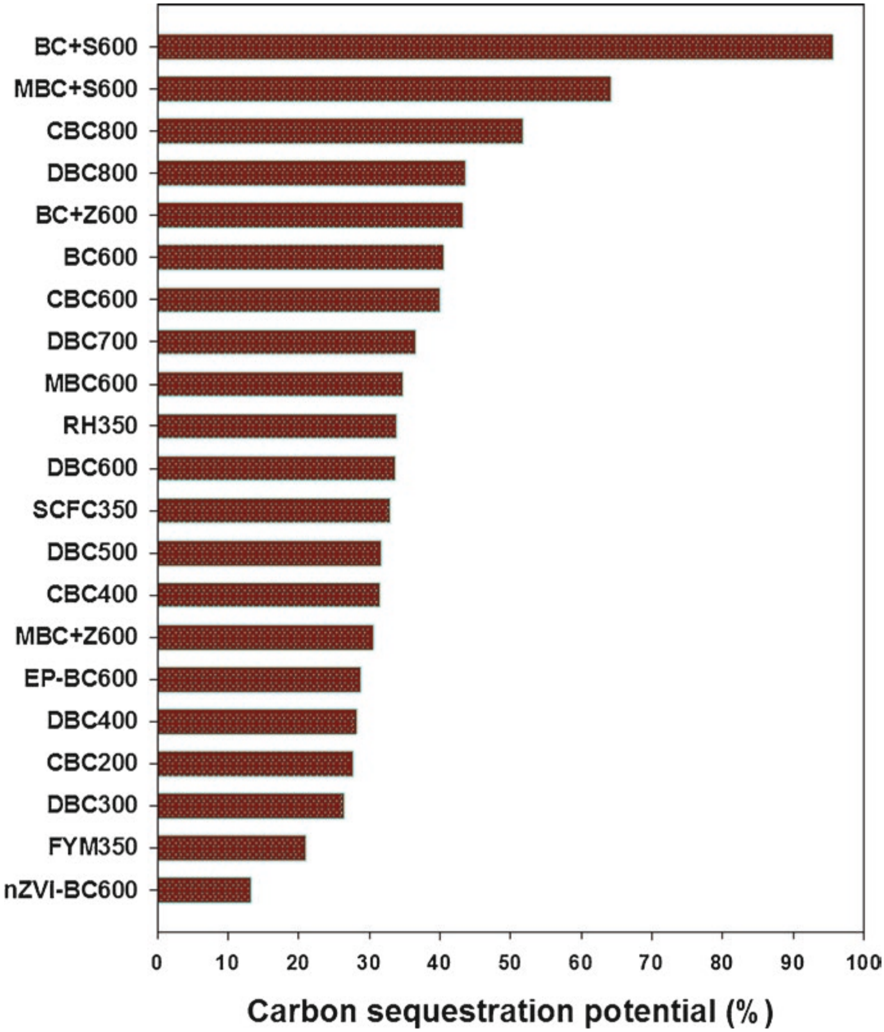

Fig. 21.3 Carbon sequestration potential of various feedstocks and biochar materials as calculated from Ahmad et al. (2018, 2019), Al-Wabel et al. (2013) and Usman et al. (2015). (The numeric values following the biochar name represent pyrolysis temperature in °C; while, DBC: date palm tree waste derived biochar; CBC: Conocarpus waste derived biochar; RH: rice husk biochar; FYM: farmyard manure biochar; nZVI-BC: nano zero valent iron composited biochar; SCFC: sugarcane filter cake biochar; BC: date palm waste biochar; MBC: milled date palm waste biochar; BC+S: date palm waste biochar composite with silica; MBC+S: milled date palm waste biochar composite with silica; BC+Z: biochar composite with zeolite; MBC+Z: milled biochar composite with zeolite; and EP-BC: date palm waste biochar composite with eggshell power)

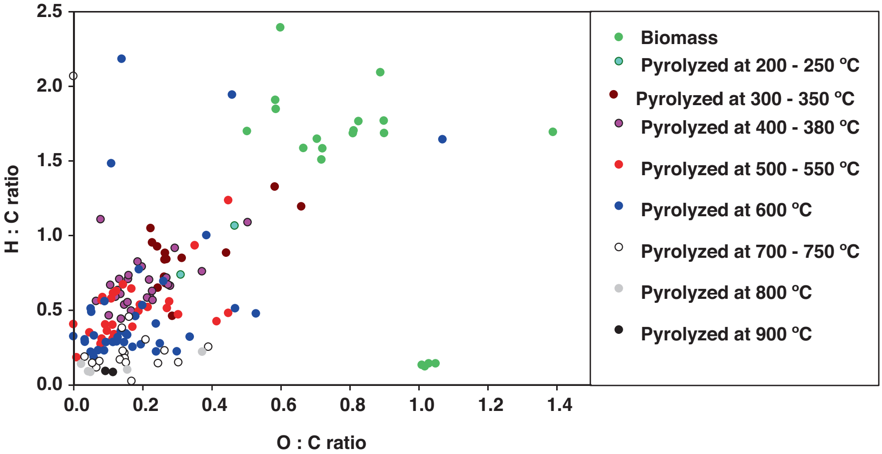

Fig. 21.4. van Krevelen diagram of elemental ratios of H/C and O/C of various feedstocks and biochar materials

significantly with the increase in the pyrolyzing temperature. It was observed that the biochars pyrolyzed at 700–900 °C showed the lowest H/C and O/C ratios regardless of the type of the feedstock suggesting higher aromaticity and stability. However, oil palm kernel and banana peel derived biochars pyrolyzed even at 500–600 °C exhibited higher H/C and O/C molar ratios, compared with all the other biochars pyrolyzed at the same temperature, suggesting that origin of feedstock could also contribute in the stability of the biochar. With the increase in the pyrolysis temperature, the materials go under depolymerization and dehydration and result in the evolution of H and O, which subsequently reduce the H/C and O/C molar ratios. Therefore, any change in H/C and O/C molar ratio indicate the chemical reaction pathways during the pyrolyzing process. The O/C and H/C ratios are a function of the composition and type of feedstock, pyrolysis temperature and residence time and post-pyrolysis conditioning; thus, it is considered as the strongest indicator to estimate the stability and recalcitrance of biochar.

21.3.2.3 Proximate Analyses

The proximate analyses such as fixed carbon (FC) and volatiles are considered very important for the estimation of the recalcitrance of biochar. The contents of FC are directly related to stable C contents within the biochar matrix. According to Brassard et al. (2016), the biochar with higher levels of FC has more potential to mitigate climate change. It has been reported that FC increases with increase in pyrolysis temperature and stable C contents and with a decrease in the O/C molar ratio (Crombie et al. 2013; Spokas 2010). Contrarily, the volatiles are directly related to mineralizable and labile C contents, and therefore higher volatiles indicate lower stability of the biochar and vice versa (Zimmerman 2010). As the FC and volatiles are determined as percentages of the total biochar mass, therefore, changes in ash contents due to the difference in feedstock type and pyrolysis conditions result in miscalculation in estimating the recalcitrance of the biochar. Based on the FC, volatiles, O/C and H/C ratios, Spokas (2010) presented a criteria that the biochars with volatiles >80% have no C sequestration potential, biochars with volatiles <80%, O/C > 0.2 and H/C > 0.4 have medium C sequestration potential, and biochars with volatiles <80%, O/C < 0.2 and H/C < 0.4 have the highest C sequestration potential. Additionally, by combining the volatiles with FC contents, the criteria suggested that the biochars with volatiles/FC ratio < 0.88 possess half-life of more than 1000 years, while the biochars with volatiles/FC ratio of 0.88–3.0 possess a half-life of 100–1000 years (Klasson 2017). We gathered the proximate analyses of 64 materials (feedstock and their corresponding biochars) from the previously published articles (Table 21.1). It was noticed that 26.56% of the materials exhibited extremely highest C sequestration potential showing volatiles/FC ratios under 0.3, while 31.25% of the materials were possessing highest C sequestration potential showing volatiles/FC ratios in the range of 0.3–0.88. About 23.44% of the materials exhibited volatiles/FC ratios in the range of 0.88–3.0 indicating moderate C sequestration potential, while 18.75% of the materials did not demonstrate any C sequestration potential as their corresponding volatiles/FC ratios were above 3.00. Timothy grass residue, wheat straw, oil palm kernel shell, pinewood residue, orange peel, date palm tree waste, douglas fir wood, banana peel, hybrid poplar wood, and silica modified biochar exhibited the highest C sequestration potential among all the presented materials. It was noticed that un-pyrolyzed biomass was exhibiting no to medium C sequestration potentials. Hence, it was stated that the pyrolysis temperature, as well as the type of the feedstock, were important parameters influencing the FC and volatiles of the materials consequently affecting the C sequestration potential.

21.4 Biochar Application for Negative Emission Technologies

The world climate keeps changing as the GHG emissions to the atmosphere increase (IPCC 2007). The CO_2, N_2O and CH_4 gas are the major constituents of greenhouse gases causing global warming effect. Employing negative emission technology for combating the atmospheric CO_2 emission in a view of permanently removing it from the atmosphere was reported as a means of reducing global warming to a level lower than 2 or 1.5 °C before this century comes to an end (UNEP 2016). Biochar, a product of the pyrolysis of biomass in the absent or limited air has been identified as one of the effective negative emission technologies when applied to the soil as an amendment (UNEP 2016), exhibiting 0.7 Gt $C_{eq.}$ year^{-1} as negative emission capacity (Smith 2016). Even though the usefulness of biochar goes beyond this, it has been reported to improve soil condition in terms of its fertility status and hydro-physical properties of soil as well as nutrient uptake, hence, improving crop

Table 21.1 Proximate analyses of various feedstock and biochar materials

Feedstock type	Pyrolysis temp. (°C)	Ash%	Volatiles (%)	Fixed Carbon (%)	Volatiles/ FC	References
Materials with extremely high carbon sequestration potential						
Timothy grass residue	600	7.6	8.7	83	0.104819	Nanda et al. (2014)
Wheat straw residue	600	8.7	9.1	81.7	0.111383	Nanda et al. (2014)
Oil palm kernel shell	700	3	10	85	0.117647	Liew et al. (2018)
Pinewood residue	600	3.7	10.6	84.9	0.124853	Nanda et al. (2014)
Orange peel	500	9.4	11.9	71.7	0.165969	Lam et al. (2018)
Date palm tree waste	600	38.68	8.93	51.39	0.173769	Ahmad et al. (2019)
Douglas fir wood	600	1.13	15.72	83.15	0.189056	Suliman et al. (2016)
Douglas fir wood	550	1.01	19.16	79.83	0.24001	Suliman et al. (2016)
Milled date palm tree waste	600	38.27	10.05	50.1	0.200599	Ahmad et al. (2019)
Banana peel	500	10.5	15.5	67.6	0.22929	Lam et al. (2018)
Douglas fir bark	600	8.85	17.25	73.89	0.233455	Suliman et al. (2016)
Wood hybrid poplar	600	7.17	17.81	75.01	0.237435	Suliman et al. (2016)
Oil palm kernel shell	600	3	19	76	0.25	Liew et al. (2018)
Silica impregnated date palm tree waste	600	71.39	5.76	22.32	0.258065	Ahmad et al. (2019)
Wood hybrid poplar	550	7.25	20.37	72.38	0.281431	Suliman et al. (2016)
Douglas fir bark	550	8	20.61	71.39	0.288696	Suliman et al. (2016)
Douglas fir wood	500	0.78	23.12	76.1	0.303811	Suliman et al. (2016)
House demolishing wood waste	800	29.82	17	53.18	0.319669	Paz-Ferreiro et al. (2014)
Sewage sludge	400	52	21.3	26.7	0.797753	Song et al. (2014)
Sewage sludge	450	55.6	17.3	27.1	0.638376	Song et al. (2014)
Sewage sludge	500	57.6	14.2	28.2	0.503546	Song et al. (2014)

(continued)

Table 21.1 (continued)

Feedstock type	Pyrolysis temp. (°C)	Ash%	Volatiles (%)	Fixed Carbon (%)	Volatiles/ FC	References
Sewage sludge	550	58.5	13	28.5	0.45614	Song et al. (2014)
Burcucumber plant	700	43.72	13.55	42.39	0.319651	Rajapaksha et al. (2014)
Douglas fir wood	400	0.67	36.14	63.2	0.571835	Suliman et al. (2016)
Douglas fir wood	450	0.85	28.43	70.75	0.401837	Suliman et al. (2016)
Wood hybrid poplar	350	3.6	42.15	54.34	0.775672	Suliman et al. (2016)
Wood hybrid poplar	400	5.28	29.96	21.75	0.462703	Suliman et al. (2016)
Wood hybrid poplar	450	6.31	25.62	68.06	0.376433	Suliman et al. (2016)
Wood hybrid poplar	500	7.03	22.69	71.27	0.318367	Suliman et al. (2016)
Douglas fir bark	400	6.21	34.61	59.18	0.584826	Suliman et al. (2016)
Douglas fir (Pseudotsuga Menziessii) bark	450	7.31	31.09	61.6	0.504708	Suliman et al. (2016)
Douglas fir bark	500	7.57	26.01	66.42	0.391599	Suliman et al. (2016)
Silica impregnated milled date palm tree waste	600	75.57	7.59	16.12	0.470844	Ahmad et al. (2019)
Zeolite impregnated date palm tree waste	600	68.37	9.49	22.14	0.428636	Ahmad et al. (2019)
Oil palm kernel shell	500	3	35	61	0.57377	Liew et al. (2018)
Banana peel	400	9.2	34.2	52.4	0.652672	Lam et al. (2018)
Orange peel	400	6.9	33.4	55.2	0.605072	Lam et al. (2018)
Materials with high carbon sequestration potential						
Wheat straw residue	Un-pyrolyzed	2.3	69.2	25.1	2.756972	Nanda et al. (2014)
Douglas wood	350	0.6	49.82	49.58	1.004841	Suliman et al. (2016)
Douglas fir bark	350	4.72	43.78	51.5	0.850097	Suliman et al. (2016)
Date palm tree waste	Un-pyrolyzed	8.33	62.22	24.47	2.542705	Ahmad et al. (2019)

(continued)

Table 21.1 (continued)

Feedstock type	Pyrolysis temp. (°C)	Ash%	Volatiles (%)	Fixed Carbon (%)	Volatiles/ FC	References
Zeolite impregnated milled date palm tree waste	600	80.27	10.87	8.86	1.226862	Ahmad et al. (2019)
Nano zero valent iron with date palm tree waste	600	60.87	18.88	10.64	1.774436	Ahmad et al. (2018)
Oil palm fruit bunches	Un-pyrolyzed	4	60	30	2	Liew et al. (2018)
Oil palm mesocarp fibers	Un-pyrolyzed	3	60	30	2	Liew et al. (2018)
Oil palm fronds	Un-pyrolyzed	4	51	33	1.545455	Liew et al. (2018)
Oil palm trunks	Un-pyrolyzed	6	47	39	1.205128	Liew et al. (2018)
Oil palm kernel shell	Un-pyrolyzed	4	58	34	1.705882	Liew et al. (2018)
Banana peel	Un-pyrolyzed	8.3	53.6	31.3	1.71246	Lam et al. 2018
Orange peel	Un-pyrolyzed	3	50.9	34.8	1.462644	Lam et al. (2018)
Banana peel	300	3	47	46.6	1.008584	Lam et al. (2018)
Orange peel	300	4	48.3	40.9	1.180929	Lam et al. (2018)
Materials with moderate carbon sequestration potential						
Sewage sludge	600	78.53	16.7	4.77	3.501048	Paz-Ferreiro et al. (2014)
Burcucumber plants	300	31.24	52.3	13.61	3.842763	Vithanage et al. (2014)
Timothy grass residue FS	Un-pyrolyzed	1.9	71.6	21.5	3.330233	Nanda et al. (2014)
Milled date palm tree waste	Un-pyrolyzed	8.36	66.36	20.5	3.237073	Ahmad et al. (2019)
Silica impregnated date palm tree waste	Un-pyrolyzed	25.68	51.86	13.4	3.870149	Ahmad et al. (2019)
Burcucumber plants	700	54.29	34.71	8.13	4.269373	Vithanage et al. (2014)
Pinewood residue	Un-pyrolyzed	1.6	75.5	17.4	4.33908	Nanda et al. (2014)
Zeolite impregnated date palm tree waste	Un-pyrolyzed	28.91	56.68	13.59	4.170714	Ahmad et al. (2019)
Silica impregnated milled date palm tree waste	Un-pyrolyzed	28.41	58.33	9.89	5.897877	Ahmad et al. (2019)

(continued)

Table 21.1 (continued)

Feedstock type	Pyrolysis temp. (°C)	Ash%	Volatiles (%)	Fixed Carbon (%)	Volatiles/ FC	References
Zeolite impregnated milled date palm tree waste	Un-pyrolyzed	26.5	62.77	9.44	6.649364	Ahmad et al. (2019)
Burcucumber plants	Un-pyrolyzed	16.82	66.54	6.49	10.2527	Vithanage et al. (2014)
Deinking sewage sludge	600	21.81	32.97	2.22	14.85135	Paz-Ferreiro et al. (2014)

productivity (He et al. 2016; Major et al. 2010; Novak et al. 2009a). However, the prosperity of biochar produced from corn stover and yard waste to drastically reduced GHG when applied as soil amendment was reported by Roberts et al. (2010). The sequestration of C within the soil contributes to the major (62–66%) reduction of GHG emission. GHG emission was reported to have reduced by two to fivefold following the application of biochar to an agricultural field compared to burning it for the purpose of fossil fuel (Gaunt and Lehmann 2008). The ability of biochar to depress GHG emission is mainly due to its ability to sequester carbon within the soil (Gaunt and Lehmann 2008; Roberts et al. 2010).

21.4.1 Reduction in CO_2 Emissions with Biochar

Agriculture, forestry and other forms of land use which include the removal of trees in preparation for arable crop production and pastoral farming leads to a greater emission of GHG such as CO_2 to the atmosphere. These activities amount to 24% of the total global GHG emission (Smith et al. 2014; Wollenberg et al. 2016). Biochar application as a soil amendment has been reported to sequester C and thereby reduce the release of CO_2 to the atmosphere (Lehmann 2007a; Zhang and Ok 2014) due to its lower rate of mineralization and its residence time is long. The biomass carbon which is known to be less stable is converted to a more stable carbon after pyrolysis process in the production of biochar and could stay in the soil for centuries (Lehmann 2007a). The decomposition of plants releases the CO_2 captured by the plant through photosynthesis to the atmosphere (Lal et al. 2007; Lehmann and Joseph 2015; Lehmann et al. 2011; (USBI 2014). In this case, the release of CO_2 trapped by the plant through photosynthesis can be minimized by transforming the biomass into biochar since it is in the form of a stable carbon in the biochar material which is less mineralized, hence, leading to reduced CO_2 emission (Lal et al. 2007; Lehmann and Joseph 2015; Liu et al. 2015; (USBI 2014). An estimation of 0.1–0.3 billion tons of CO_2 emission per year could be prevented when carbon is being stored in biochar (Liu et al. 2015). Giving a look on biochar application rate of 10–100 t ha^{-1}, with an approximate of 50–78% C concentration, suppose cropland covers an area of

1411°×°10^6 ha globally, an estimate of 7–110 giga-ton of biochar-carbon could be stored globally (Chan et al. 2008; Lehmann et al. 2009; Novak et al. 2009b).

There is variation in the influence of biochar on CO_2 evolved when applied as a soil amendment as revealed in Table 21.2. Biochar has been reported to increase CO_2 emission in treated soil when compared to the control (Brassard et al. 2018; Case et al. 2015; Castaldi et al. 2011) and also to decrease CO_2 emission (Ameloot et al. 2014; Grutzmacher et al. 2018; Azeem et al. 2019). As reported by Rogovska et al. (2011) following a column incubation experiment which lasted for 500 days, CO_2 was significantly increased in the biochar treatment soil when compared to the control where biochar was not applied. According to the author, the significant increase in CO_2 release was attributed to a faster rate of decomposition of soil organic matter which is due to (i) improvement in soil aeration resulting from the reduced bulk density of the soil treated with biochar thereby leading to increased activity of the soil aerobic microbes and (ii) increased colonization of microorganisms resulting in faster decomposition of organic matter. In general, the rate of biochar mineralization resulting in CO_2 emission is higher at the first stage of application as reported by Brassard et al. (2018), who noticed a higher rate of mineralization within first 10 days of biochar application and reduced after this period till the end of the 25 days incubation experiment.

The higher rate of biochar decomposition within the first days of application has been ascribed to the labile organic C being mineralized because of their simpler structures with lower masses (Troy et al. 2013; Spokas et al. 2009) and the inorganic C being hydrolyzed (Fidel et al. 2017). Also, Ameloot et al. (2013a) recorded high emission of CO_2 during the first days of biochar application and could be due to the priming of native soil organic carbon pool, and the activation of soil organisms by biochar aiding the biological decomposition of biochar materials. Pyrolysis temperature, feedstock, Soil type, (Ameloot et al. 2014; Brassard et al. 2018) as well as biochar application rates (Ameloot et al. 2014; Zhang et al. 2012; Zhang et al. 2017) are possible factors affecting the extent of effect biochar has on CO_2 emission. Application of biochar at higher rates increases the suppression of CO_2 emission (Spokas et al. 2009). Regarding the influence of pyrolysis temperature on CO_2 emission, Carbon dioxide emission decreases with increasing pyrolysis temperature as reported by Feng and Zhu (2017) after applying 3% (W/W) of rice straw biochar to the soil in an incubation study. Also, Zimmermann et al. (2011) observed that at lower pyrolysis temperature (250, 400 °C), biochar produced aid CO_2 respiration compared to the one produced at a higher temperature (525, 650 °C) which hinders C mineralization in the soil. Similarly, Junna et al. (2014) observed a progressive decrease in C mineralization with increasing pyrolysis temperature (from 300 to 600 °C) found that the. The authors attributed this observation to labile organic carbon declination from 133 mg g^{-1} to 68 mg g^{-1} for biochars produced at 300 °C and 600 °C respectively. Biochar produced at higher temperature is characterized by lower labile C and higher carbonization (Bruun et al. 2011a; Cross and Sohi 2011), this results in a lower priming effect on CO_2 emission in biochars produced at higher temperature whereas biochars produced at lower temperature have a higher priming effect on CO_2 emission (Zimmerman et al. 2011). Biochars produced at higher

Table 21.2 Influence of biochar application as a soil amendment on Greenhouse gas (CO_2, N_2O, and CH_4) emission

Study type	Study duration	Soil order	Soil	Biochar feedstock	Biochar pyrolysis temperature (°C)	Application rate	Change in CO_2	Change in N_2O	Change in CH_4	References
							%			
Greenhouse	125 day	Entisol	Sandy loam	Sugar maple and yellow birch wood	350–600	–	–	–	−39	Khudzari et al. (2019)
Field	6 month	Inceptisol	Loamy	Eucalypt wood	350	6.25 t/ha	14.8		−70.6	Thammasom et al. (2016)
						12.50 t/ha	−11.5		−172.2	
						18.75 t/ha	15.4		−181.8	
						25.00 t/ha	8.0		−400.0	
Incubation	8–9 week	–	Sandy clay loam	Oak and cherry	400	49 t/ha	−30.9	–	–	Ameloot et al. (2014)
			Clay loam	Pruning orchard	500	30 t/ha	−15.4			
			Silt loam	Pruning orchard		30 t/ha	−12.9			
			Silt loam	Beech, hazel, oak, and birch		20 t/ha	−80.5			
Field	10 month	Gleysol	Clay loam	Tree pruning	650	–	–	−107.6	–	Krause et al. (2018)

Study type	Study duration	Soil order	Soil	Biochar feedstock	Biochar pyrolysis temperature (°C)	Application rate	Change in CO_2	Change in N_2O	Change in CH_4	References
							%			
Incubation	45 day	–	Loamy sand	Wood	516	2% (w/w)	510.8	1251.9	–	Brassard et al. (2018)
					644		279.4	300.0		
				Switchgrass	459		1703.9	75.0		
					591		697.1	166.7		
				Pig manure	526		2086.3	2011.1		
					630		1439.2	735.2		
			Silt loam	Wood	516		29.1	−72.7		
					644		33.3	−112.2		
				Switchgrass	459		107.4	−869.1		
					591		37.6	−139.7		
				Pig manure	526		188.9	287.3		
					630		125.4	72.6		
Field	12 month	Ultisol	Sandy loam	Pine chip	550	30 t/ha		48		Lan et al. (2019)
Field	2 year	Inceptisol	–	Wheat straw	350–550	10 t/ha	−016.6	−45.2	−15.5	Zhang et al. (2012)
						20 t/ha	−10.1	−80.0	54.1	
						40 t/ha	3.9	−125.0	38.2	
Field	2 year	Anthrosols	Silt clay loam	Wheat straw	350–550	8 t/ha	−17.4	−58.8	50.0	Zhang et al. (2017)
						16 t/ha	−20.8	−80.0	−100	
Pot	1 year	Inceptisol	–	Cornstalk	300	24 t/ha	–	–	−417.8	Feng et al. (2012)
					500				−521.3	
		Ultisol			300				−222.0	
					500				−190.1	

(continued)

Table 21.2 (continued)

Study type	Study duration	Soil order	Soil	Biochar feedstock	Biochar pyrolysis temperature (°C)	Application rate	Change in CO_2	Change in N_2O	Change in CH_4	References
							%			
Incubation	–	–	Sandy loam	Hardwood trees	400	28 t/ha	75	−91	–	Case et al. (2015)
Incubation	100 day	Mollisol	Silt loam	Sawdust	500	24–720 t/ha	Reduced	Reduced	Reduced	Spokas et al. (2009)
Field	2 year	–	Silty loam	Beech, hazel, oak, and birch	500	3–6 kg/m^2	Increased	Reduced	–	Castaldi et al. (2011)
Field	2 year	Inceptisol	–	Wheat straw	450	20 t/ha	8.0	−44.4	−17.7	Zhang et al. (2016)
						40 t/ha	6.5	−50.3	−27.5	
Field	4 month	Alfisol	Silt loam	Oakwood	650	7.5 t/ha	−43	−92	−56	Mukherjee et al. (2014)
Field	4 year	Oxisol	Sandy loam	Wheat straw	350–500	5, 10 and 20 t/ha	–	−17.89	−70.02*	Qin et al. (2016)
Field	3 year	Cambisol	Sandy loam	Wood chips	850	10 t/ha	−3.0	−54.0		Sun et al. (2017)
Incubation	14 day	–	–	Rice straw	300	3% (w/w)	–	−69.1	60.5	Wang et al. (2017)
					500			−97.8	7.6	
					700			−99.0	8.9	
Column	2 month	–	Silt loam	Rice straw	300	1% (w/w)	–	−27.0	–	Feng and Zhu (2017)
					500			−66.0		
					700			−74.0		
Incubation	60 day	–	Clay loam	Chicken manure and sewage sludge.	400	5 g C/kg	−72.4	−87.0	–	Grutzmacher et al. (2018)
Incubation	100 day	Luvisol	Silty loam	Pine sawdust	550	1.5% (w/w)	−16.4	−27.5	Ns	Pokharel et al. (2018)

Study type	Study duration	Soil order	Soil	Biochar feedstock	Biochar pyrolysis temperature (°C)	Application rate	Change in CO_2	Change in N_2O	Change in CH_4	References
							%			
Field	120 day	–		Rice husk	350	2 t/ha	–	55.8	–	Yoo et al. (2018)
Incubation	32 week	–	Sandy loam	*Fraxinus excelsior*, *Fagus sylvatica*, and *Quercus robur*.	–	3% (w/w)	–	−60	–	Martin et al. (2015)
Field	2 year	–	Sandy loam	Bagasse	350	0.25% C/ha	−84.1	–	–	Azeem et al. (2019)
						0.5% C/ha	−68.8			

temperature are characterized with having lower H/C_{org} and O/C_{org} ratios compared to those produced at lower temperature (Al-Wabel et al. 2013; Brassard et al. 2018; Junna et al. 2014; Luo et al. 2011; Sun et al. 2014a, b) and this could result in lower mineralization of biochar produced at higher temperature. In addition, biochars produced at higher pyrolysis temperature have a larger surface area (Jindo et al. 2014), for example, biochar produced from pine sawdust at 550 °C had a surface area of 293 m^2 g^{-1} (Lou et al. 2016). As reported by Ameloot et al. (2013b), biochars with a surface area greater than 200 m^2 g^{-1} are likely to hinder soil organic matter mineralization, hence, reduce CO^2 emission. This is because these biochars could take up soluble contents of the organic materials in their small pores making it difficult for microorganisms to have access to these materials for further mineralization. Soil type influencing biochar performance on CO_2 emission could be noticed in the 100-day incubation study of Pokharel et al. (2018) where biochar produced from Pine sawdust at 550 °C was applied to forest and grassland soil, the biochar had a profound effect in decreasing CO_2 emission in the forest soil whereas it has no effect on the grassland soil. The author associated this outcome to the forest soil considerably higher in soil organic matter). Also, in an incubation study, Wu et al. (2018) observed a significant increase in CO_2 release in the olive biochar amended acidic sandy soil compare to N fertilizer (ammonium sulfate) treatment, while amendments have no effect in the alkaline soul. According to the authors, it could be as a result of labile C present in the olive biochar (Kuzyakov et al. 2009), which categorically mineralized in soil with low pH. Application of biochar at higher rates increases the suppression of CO_2 emission (Spokas et al. 2009). Another factor affecting CO_2 emission is the N content of biochar. Soil respiration is favored by a higher amount of soil N (Oertel et al. 2016).

There is a higher portion of sequestered C when biochar C is applied to soil compared to other forms of an organic amendment like manure which exhibits a faster rate of mineralization and emit CO_2 (Troy et al. 2013). In a 65 days incubation experiment where wheat straw and its derived biochar where applied as treatments, Bruun et al. (2012a, b) observed that the percentage of biochar C lost in form of CO_2 at the end of the experimental period was 2.9% whereas the percentage of wheat straw C lost was 53%. Within 2 years of biochar application, 2.2% of biochar C was estimated to have been lost by respiration according to Major et al. (2010). However, in the second year of the experiment, there is a reduced rate of CO_2 emission as stimulated by biochar application, and this could imply that mineralization of C resulting in CO_2 losses reduces with time (Major et al. 2010).

In conclusion, biochar has great potential in the sequestration of carbon in soils, hence reducing CO_2 emission.

21.4.2 Reduction in N_2O Emissions with Biochar

Nitrous oxide (N_2O) is well known to be a potent greenhouse gas and as such contributes widely to the depletion of the ozone layer (Ravishankara et al. 2009). The concentration of N_2O in the atmosphere keeps increasing and was estimated to attain a value of 328 ppb in 2016 which majorly result from anthropogenic activities interfering the nitrogen cycle (Davidson 2009; WMO 2016). Agricultural activities are the major cause of overall anthropogenic N_2O release (Smith et al. 2008) leading to the emission of 4.3–5.8 Tg N_2O year^{-1}, which necessitates the development of effective negative emission technology to combat the ever-increasing N_2O gas emission (Butterbach-Bahl et al. 2013). The emission is governed by some factors which include nitrogen fertilizer (inorganic) application, labile organic carbon, moisture content of soil and soil temperature (Firestone and Davidson 1989). N_2O production in the soil is majorly through nitrogen transformation processes which include denitrification, nitrification and nitrifier-denitrification (Kool et al. 2011; Butterbach-Bahl et al. 2013) mediated by soil microbes where denitrification process is generally identified as one of the most vital N_2O generating mechanisms (Davidson 2009). In soil with limited oxygen, saturated with water, nitrate (NO_3^-) is being reduced to molecular nitrogen (N_2); this process is termed as denitrification and is more rampant following soil fertilizer application resulting in a bioavailability of nitrogen compound (Davidson 2009). N_2O is unavoidably generated in the midway of the process of denitrification. The conclusive phase of denitrification, the conversion of N_2O to N_2, is the only way N_2O is being stored biologically (Thomson et al. 2012). The enzyme involved in this last phase is known as nosZ (Philippot et al. 2007) which is oxygen sensitive and as well sensitive to acidic soil in terms of its functionality (Liu et al. 2014; Zumft and Kroneck 2006). On account of this, the reduction of N_2O to N_2 is often diminished resulting in higher production of N_2O gas.

Biochar as soil amendment has been proposed to be a tool for the mitigation of N_2O release as reported from different studies where N_2O emission decreased following biochar application (Cayuela et al. 2013; Harter et al. 2014; Singh et al. 2010; van Zwieten et al. 2014) though it increases N_2O emission in some cases (Yanai et al. 2007; Bruun et al. 2011b). The feedstock of biochar, soil texture as well as N fertilizer type were observed to be factors affecting the extent biochar effect on N_2O emission (Clough et al. 2013) through the responsible mechanism is still yet to be fully understood (Cayuela et al. 2013, 2014; Clough et al. 2013). In incubation studies, increase in soil pH following biochar application has been proposed to be one of the major drive responsible for N_2O mitigation (Obia et al. 2015; van Zwieten et al. 2010; Zheng et al. 2012) since high soil pH aids reduction in N_2O gas emission (Baggs et al. 2010; Cuhel et al. 2010). In addition, incubation studies revealed that reduction in N_2O release following biochar application simultaneously increased nosZ bearing denitrifiers activities with a shift in the community composition of denitrifiers (Anderson et al. 2014; Harter et al. 2014, 2016; van Zwieten et al. 2014). Through a molecular fingerprint method, biochar was observed to be capable of affecting microorganism community composition (Anderson et al. 2011; Chen et al. 2013). Also, biochar addition can affect the functional communities that contribute to degradation and transformation of nitrogen (Chen et al. 2015; Kolton et al. 2011). Another mechanism for N_2O mitigation following biochar application is the immobilization process in soil amended with biochar which limits mineral N availability to soil microbes responsible for nitrification and denitrification (Bruun et al. 2012a; Case et al. 2012; Nelissen et al. 2014). Mineralization or nitrification of N may affect the availability of inorganic N. After the addition of biochar, the rise in the rate of mineralization was associated with activated mineralization of native soil organic matter (Nelissen et al. 2012), while high soil pH of arable soil treated with biochar (Nelissen et al. 2012) and biochar absorbing inhibitive phenolic compounds as observed in forest soil (DeLuca et al. 2006) resulted in higher rates of nitrification.

Table 21.2 shows the extent to which biochar application affects N_2O emission as reported by different studies. There are mixed results on the effect of biochar on N_2O emission. However, biochar addition often leads to declination in N_2O release (Zhang et al. 2012; Case et al. 2015; Spokas et al. 2009; Castaldi et al. 2011) while it increases in few cases (Brassard et al. 2018; Yoo et al. 2018). From the table, it could be deduced that pyrolysis temperature, biochar feedstock, biochar application rate, as well as soil type, played role in the extent at which N_2O emission is affected following biochar application. As reported by Brassard et al. (2018) in a 45-day incubation study, biochar produced from switchgrass at lower pyrolysis temperature (459 °C) had lower N content compared to the one produced at higher temperature (591 °C), corresponding to the report given by Al-Wabel et al. (2013) who observed that N content in biochar increased with pyrolysis temperature. This considerably resulted in a significant decrease in N_2O release in soil treated with biochar produced at a lower temperature while soil amended with biochar produced at higher temperature did not experience a significant decrease in N2O emission. Furthermore, the author observed a profound effect of biochar on mitigating N_2O emission on the finest texture soil compared to the coarse-textured soil. This corresponds to the meta-analysis conducted by Cayuela et al. (2014) who also reported greater mitigation of N_2O gas in finest texture soil following biochar addition as it is easily subjected to denitrification when the moisture content is high.

The increasing rate of biochar application increases the N_2O emission mitigation as observed by Zhang et al. (2012) and Case et al. (2012). Following an incubation experiment which lasted for 126 days, Case et al. (2012) deduced that the declination in N_2O emission with increasing biochar addition could be associated to the decrease in the content of the extractable N-NO_3 in the amended soil. Similarly, Harter et al. (2014) reported that a decrease in the concentration of NH_4^+ and NO_3^- resulted in increased N_2O mitigation. The reduction in N related compounds could be as a result of adsorption on the surface of biochar. The sorption properties of biochar could give it the potential to adsorb compounds of N such as NH_4^+ and NO_3 which considerably alter the N cycle (Kettunen and Saarnio 2013; van Zwieten et al. 2010). Moreover, the buildup of organo-mineral complexes as well as functional groups of acid and base on the surface of biochar, together with the unusual water-ion hydrogen-bonding to the surface of the biochar pores could contribute to the adsorption of NO_3^- on the biochar surface (Kammann et al. 2015). Immobilization of compounds related to N is another means for the decrease in NH_4^+ and NO_3^- concentrations within the microbial biomass. According to Burger and Jackson (2003), the addition of C rich material such as biochar to the soil usually stimulates the activities of the microbes resulting in increasing immobilization of NO_3^-. Reports from different studies revealed that soil microbial activity is affected by biochar addition (Jenkins et al. 2017; He et al. 2016). Categorically, biochar was found to affect the population and taxonomy constitution of N_2O-reducing microorganisms attributes in soil (Harter et al. 2016). Finally, the increase in growth and activity of microbes responsible for full denitrification as a result of biochar amendment could be responsible for the reduction in N_2O emission (Anderson et al. 2011; Harter et al. 2014).

21.4.3 Reduction in CH_4 Emissions with Biochar

To conquer the global warming effect, strategies must be put in place to mitigate greenhouse-gas emissions. After CO_2, methane (CH_4) is recognized as the second most influencing gas affecting global warming: it is estimated to be 78% to global CO_2 emission (Tsuruta et al. 1998). About 10–12% of the overall greenhouse gases emission as a result of anthropogenic activities is from agricultural practices where CH_4 emission amount to 50% of these gases (Smith et al. 2007). Since 1750, emission of CH_4 has experienced an increase of 151% (IPCC 2007), which is still experiencing an increasing rate of 0.003 micromol per mol per year (Butenhoff and Khalil 2007; Bloom et al. 2010). Methane is expected to increase further due to the increase in food demand, to results in the cultivation of more land for agricultural purposes: agricultural production is expected to cover an additional 70 million (Alexandratos and Bruinsma 2012). Water-logged fields are one of the main sources of global CH_4 emission. These fields have been estimated to release 25–54 Tg CH_4 annually (Sass 1994), and this amount 4–9% of the overall global emission of CH_4 which is 598 Tg (IPCC 2001). Therefore, reducing the CH_4 emission from paddy soil could significantly reduce the global greenhouse gases leading to global warming.

Methanogenic archaea is responsible for the biological production of CH_4 in the paddy field. In the process of methanogenesis, organic matter is degraded in the absence of oxygen by different kind of bacteria to compounds which include CO_2, H_2, and acetates otherwise known as methanogenic substrates. There is further production of CH_4 by methanogenic archaea (Watanabe et al. 2007). On the other hand, methanotrophic proteobacteria which depend solely on CH_4 for its carbon and energy source consumes part of the CH_4 produced while the remaining is emitted to the atmosphere. In soil depleted of oxygen, at least 90% of the entire CH_4 produced is oxidized by methanotrophic proteobacteria (Bosse and Frenzel 1997). On this note, CH_4 production in paddy soil can be reduced by limiting the activity of methanogenic archaea, and/or increasing the activity of methanotrophic proteobacteria.

From Table 21.2, reports from different studies showed that biochar is capable of increasing (Zhang et al. 2012; Wang et al. 2017), decreasing (Thammasom et al. 2016; Feng et al. 2012; Qin et al. 2016) and having no significant effect (Pokharel et al. 2018) on the emission of CH_4 from soils. The sorption properties of biochar, capable of adsorbing CH_4 to its surface could be one of the mechanisms responsible for biochars effect on reducing CH_4 emission (Yaghoubi et al. 2014). Also, enhanced soil aeration as a result of biochar amendment, which may enhance the uptake of CH_4 could be another mechanism (Van Zwieten et al. 2010; Karhu et al. 2011). On the other hand, in an oxygen-limited environment, the readily oxidizable C of biochar may serve as a methanogenic substrate, hence, enhancing the production of CH_4 (Wang et al. 2012). Furthermore, the uptake of CH_4 by methanotrophs at the interface of oxic/anoxic in oxygen limit environments is enhanced by biochar, hence, reducing the emission of CH_4 through the biofilter function of CH_4 uptake (Feng et al. 2012; Reddy et al. 2014).

There are many factors responsible for the degree of CH_4 emission in soil treated with biochar (Lehmann and Rondon 2006). These factors include the biochar production method (Lehmann 2007b), feedstock used for the production, and the properties of soil. Since the emission of CH_4 from water-logged soil mainly depends on methanotrophic proteobacterial and methanogenic archaeal, therefore, the degree of CH_4 release is due to the response of these microbes to biochar amendment.

Methanogens compete with ferric iron reducers for hydrogen or acetate following the addition of biochar with larger surface area, as this process could be a possible mechanism for the inhibition of methanogens (Lovley and Phillips 1987). Increase in the population of Clostridia, iron reducing bacteria after the addition of biochar as an amendment was reported by Weber et al. (2006), with a greater amount for biochar produced at higher temperature (700 °C) compare to the one produced at 500 °C (Wang et al. 2017). Biochar produced at higher temperature has a larger surface area which promotes the shuttling of electron between the insoluble electron acceptor (for example, oxide or hydroxide of Fe^{III}) and microorganisms thereby enhance the reduction of Fe^{III} (Kappler et al. 2014), and these might compete for electron for the production of CH_4, resulting in the reduction of CH_4 emission.

21.5 Future Research and Opportunities

About 120 Gt of C is being fixed into plants due to photosynthesis each year and about 13 Gt of dry biomass is being produced annually (Lee et al. 2010). By deployment of advanced biomass pyrolysis technologies, this huge amount of biomass could be turned into valuable biochar which in return can fix a huge amount of atmospheric C into the soil. According to an estimate, the utilization of each ton of biomass to produce biochar could fix 800–900 kg of CO_2 (Roberts et al. 2010). However, the concept of biomass pyrolysis is still in the early developmental stage and requires a substantial amount of research before practical and commercial application. It is very important to develop a fully smokeless technology for biomass pyrolysis featured by converting syngas into clean energy. Secondly, the produced bio-fuel quality must be improved for practical implication and proper utilization. Thirdly, more attention is required for contaminant-free biochar production technology and soil application to assure. Therefore, a great deal of research is required to optimize the pyrolysis techniques which could result in lower smoke emissions and higher recalcitrance.

To cope with the aforementioned research gaps, various techniques have been used by different researchers. For instance, biochar fabrication with foreign materials has resulted in prolonged half-life and higher C sequestration to mitigate global climate changes. Li et al. (2014) synthesized biochar composite with $Ca(H_2PO_4)_2$ mineral and observed improved C retention ability of biochar and enhanced C stability which ultimately favored long term C sequestration, while acidic $Ca(H_2PO_4)_2$ treatment of biochar showed ability to restore alkaline soil and increased the soil fertility and C sequestration. Likewise, Ahmad et al. (2019) observed that silica composited biochar exhibited the highest recalcitrance and C sequestration potential due to encapsulation and protection of biochar with the silica particle. Surface amination of biochar has exhibited plausible effects on biochar performance as pollutant adsorption and CO_2 (Yang et al. 2014; Adelodun et al. 2014). Likewise, pyrolysis of N-rich feedstock could be an economical and helpful technique for high-quality biochar production with enhanced ability to be used as a soil amendment and to fix C from the environment (Zhao et al. 2010; Guo et al. 2013). Biochar application along with NH_4HCO_3, NH_4NO_3 and $(NH_4)_2SO_4$ has shown agricultural and environmental benefits by improving soil productivity and sequestering environmental C (Day et al. 2005, 2004; Asai et al. 2009; Lee and Li 2003). Similarly, biochar activation with specific methodologies such as acid/base treatment (Kasparbauer 2009), magnetically modified biochar (Wang et al. 2015), biochar-clay composite (Yao et al. 2014), and mineral modification of biochar (Song et al. 2014) have improved biochar characteristics as soil amendment and environmental C sequester. However, very limited work is available to develop smoke-less pyrolysis techniques and the production of designer biochars with higher carbon sequestration potential.

Further development in modern pyrolysis techniques is the need of time to mitigate climate change and to fix global environmental issues. Thus, detailed studies should be conducted to explore the implications of smoke-less pyrolysis technologies, biochar composites with fertilizer, acidic pre-treatment of biochar and addition of foreign materials such as silica for climate change mitigation. The molecular composition of various biochar composites and their interaction with clay and organic matter must be studied at the nanoscale level. The half-life of various types of biochars at field scale levels in real environmental conditions should be explored.

21.6 Conclusion

Rapid industrialization and technological development have resulted in elevated greenhouse gas emission and C depletion from soil continuously altering the climate of the planet Earth. Global warming, weather shifts, and climate change are affecting the socioeconomic systems and health of the terrestrial and aquatic life drastically. Biomass pyrolysis to produce biochar is acclaimed C negative strategy to fulfill energy requirement and mitigate climate change by sequestering atmospheric C. The aromatic structure and specific characteristics of biochar enable it to stay in the soil for thousands of years consequently resulting in enhanced C sequestrations and reduced GHG emissions. Globally, about 440 Gt of atmospheric CO_2 is being captured by land-based green plants each year due to the photosynthesis process, which can be converted into stable C sink though advanced pyrolytic techniques. Hence, the development of advanced smokeless pyrolytic technologies and designing biochars with higher recalcitrance could serve as an efficient technology for C sequestration and climate change mitigation.

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Chapter 22
The Effects of Climate Change on Human Behaviors

Senol Celik

Abstract Urbanization movements have been accelerating with the migration from rural areas, and they lead people to different productions and behaviors as a result of increasing population density and changing living standards all around the world. The environment is largely polluted by increasing urbanization, industrialization, and greenhouse gases emitted from residential areas. This causes the atmosphere to become increasingly polluted. These adversities cause environmental problems that threaten life in water, land, and air by destroying nature and changing the climate of cities. In recent years, numerous floods and earthquakes have occurred in many haphazard settlements. As a result of these disasters, many people lose their lives, get injured and become homeless. After such cases, people migrate to different settlements, their perspective change after natural disasters, and they move towards different professions and purposes. The effects of climate change on agriculture could not be ignored. Changes in precipitation and temperature as well as the increase in CO_2 levels leading to climate change have significant impacts on global agriculture. The decrease in the yield of agricultural products and the change in land structure cause people not to receive recompense for their labor and break their hopes. This leads people to different goals and occupations. In conclusion, climate change affects all areas such as health, social mobility, agriculture, economy, industry, and tourism negatively and constitutes significant changes in people's lifestyles, both material and spiritual.

Keywords Climate change · Environmental pollution · Natural disasters · Behavior

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_22

22.1 Introduction

Climate change refers to any change in climate over time, whether owing to natural instability or consequence human activity (Hasan 2015). Humans are living beings that have both biological and cultural, cognitive, and psychological structures. Humans can improve their biological, cultural, cognitive and psychological structure and characteristics with the influence of the environment (Lewis 2005).

Factors such as the earth's orbit, atmospheric components, volcanic ashes, cloud cover and solar energy reflections cause climate change (Çelik et al. 2008). These factors, alone or in combination, increase greenhouse gases. While greenhouse gases, which remain in the atmosphere for thousands of years, have an effect on global warming, those in the atmosphere have warming and cooling effects (Climate Change Science Program and the Subcommittee on Global Change Research 2003). Today, this results in climate change (Çelik et al. 2008).

Changes in climate have emerged as major changes in average temperatures, including precipitation changes, in various parts of the world, between glacial and interglacial ages (Koç and Güçer 2003; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Throughout 4.6-billion-year geological history of the Earth, there have been many changes in the climate system with natural factors and processes at all time scales from decades to millions of years (Türkeş 2008). Climate changes in different geological periods, especially through glacier movements and changes in sea level, have caused changes in the world geography and crated permanent changes in ecological systems (Türkeş 2006). Therefore, climate change can also be defined by considering human activities that increase greenhouse gas emissions (Türkeş 2008). Local impacts of climate change vary considerably. For example, temperature increases in some regions but decreases in other places, precipitation decreases, and droughts are seen in some places, whereas precipitation increases in other places (Batan and Toprak 2015).

In particular, the greatest danger to the production of human food resources, economic systems and wildlife environments is climate change which involves a few degrees of change in the average surface temperature of the earth in recent years. Only a few degrees of change can have serious consequences (Kabadayı 2010). Human beings benefit greatly from the physical environment elements they are in constant contact with. Due to industrialization and advances in technology, the impact of mankind on physical environment elements and natural resources has been much greater than in the past (Menteşe 2017).

With the ongoing process that started with industrialization, excessive use of natural resources increased and natural destruction became more evident especially in areas with intense industrialization. Human factors have been the source of many environmental problems, especially climatic changes (Gökberk 2010; Gül 2013). Natural cycle of soil, water and air deteriorates due to ecosystems such as polluted soil, water and air by humans and cannot function properly. Soil, water and air quality is becoming more and more important and environmental perception is changing in favor of the environment. Therefore, natural resources need to be used, protected and planned in a sustainable manner (Menteşe 2017).

Innumerable global problematical challenges in these days experienced in the world today lead global scientific collaborations that rely mainly on the ecosystem. The upshots increase the excessive and formidable environmental problem (Udenyi 2010). The earth's average surface temperature has increased by 10 °F just over the last century and consequently, climate intensify a serious unfavorable impact on crop yield, which has occasioned a reduction in the production of food (Houghton 2002). The effects of climate change on human health are discussed in general terms and they are subjected to speculative approaches. When investigating the effects of climate change on human health, age, gender, sanitation conditions, socioeconomic status, population structure and distribution should be taken into consideration.

In summary, meteorological factors with utmost significance that negatively affect human life can be examined as environmental pollution, air pollution, water pollution, and climate change. The occurrence of these factors both threatens human health and causes sudden waves of migration, population mobility, and decreasing social and economic status.

22.2 Factors Causing Climate Change

22.2.1 Causes of Climate Change

Earth's climate is affected by factors such as the amount of energy coming from the sun, the amount of greenhouse gases in the atmosphere, and the characteristics of the earth's surface.

Human activities affecting nature, such as deforestation and agricultural activity, especially with the industrial revolution, have led to a significant increase in emissions of natural greenhouse gases such as methane (CH_4), carbon dioxide (CO_2), and dinitrogen monoxide (N_2O). This increase in the emission of greenhouse gases to the atmosphere has led to the deterioration of the natural greenhouse effect and the warming of the atmosphere. This warming in turn has led to climate change (Demir 2009; Kanat and Keskin 2018). The effects of greenhouse gases such as carbon dioxide (CO_2), chlorofluorocarbon (CFC), methane (CH_4), nitrogen oxides (NOX), ozone (O_3) and water vapor (H_2O) causing climate change on global warming are 50%, 22%, 13%, 5%, 7%, and 3%, respectively (Zoray and Pır 2007).

CO_2, CFC and CH_4 are the greenhouse gases with the highest contribution to global warming. According to data obtained, there is an increase in the concentration of greenhouse gases. Most current greenhouse gas concentration values (Blasing 1985; Blasing 2018; IPCC 2013; Joos et al. 2013) are presented in Table 22.1.

Table 22.1 Recent Greenhouse some Gas Concentrations

Gas	Recent tropospheric concentration	GWP(100-year time horizon)	Atmospheric lifetime (years)
Concentrations in parts per million (ppm)			
Carbon dioxide (CO_2)	399.5	1	100–300
Concentrations in parts per billion (ppb)			
Methane (CH_4)	1834	28	12.4
Nitrous oxide (N_2O)	328	265	121
Tropospheric ozone (O_3)	337	–	Hours-days
Concentrations in parts per trillion (ppt)			
CFC-11 (CCl_3F)	232	4660	45
CFC-12 (CCl_2F_2)	516	10,200	100
CFC-113(CCl_2CClF_2)	72	5820	85
HFC-134a(CH_2FCF_3)	84	1300	13.4
Carbon tetrachloride (CCl_4)	82	1730	26
Sulfur hexafluoride (SF_6)	8.6	23,500	3200

GWP: The Global Warming Potential (GWP) provides a simple measure of the radiative effects of emissions of various greenhouse gases, integrated over a specified time horizon, relative to an equal mass of CO_2 emissions

The continuation of the increase in greenhouse gases in the atmosphere due to different reasons is causing global temperatures to rise even more (Andrady et al. 2008).

Since the speed and extent of the increase in greenhouse gases have not experienced before, it is estimated on global atmospheric models to understand what may lie ahead. Sufficient information has been gathered presently to test the robustness of past projections, and the findings are largely promising (Schmidt et al. 2014).

During different geological epochs, the global climate has changed in varied manners. In fact, the changes observed during this last century have been more rapid (Kondratév et al. 2003). Frankly, human activities during the latest and present centuries have propagated great quantities of greenhouse gases (GHGs) and aerosols in the atmosphere (IPCC 2014). Furthermore, remarkable forest lands have been altered across the world on account of urbanization, expansion of agricultural lands and wildfires. The innate sequestration process controlled by photosynthetic activities of plants are significantly reduced. This condition has resulted in significant alterations of the atmospheric energy balance. Moreover, the situation is aggravated by the increase of solar radiation flux, as a conclusion of the ozone layer depletion. The outcome of all these cases, explains the factual increment of the global temperature (IPCC 2013; Blasing 1985). Figure 22.1 indicates this increasing trend of the earth as the warmest during the period 2005–2018.

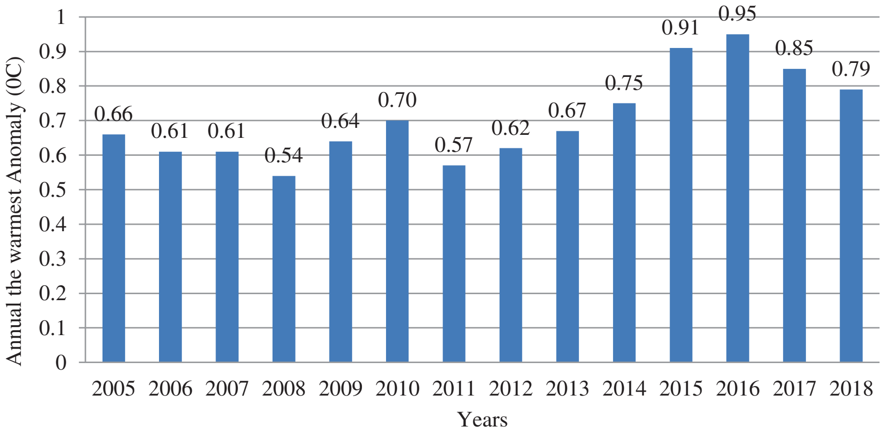

Fig. 22.1 Annual the warmest anomalies over the period 2005–2018. (Source: Global Climate Report – Annual 2015, 2016, 2017, 2018; https://www.ncdc.noaa.gov/sotc/global/201813)

22.2.2 Changes in Climate and Global Temperatures

Climate change argued in many cases may affect management efforts. Localizing climate change concerns would be a major step towards in terms of setting international targets. Agency responses on knowledge about climate change, its causes and effects demonstrate reasonable understanding of the phenomenon. Responses on the perception of climate indicators diversified among the agency respondents whereas the major themes extensively discussed were rainfall and drought (Sarpong and Anyidoho 2012).

During 2018, 11 of 12 monthly global land and ocean temperature departures from average ranked among the five warmest for their respective months, giving way to the fourth warmest year in NOAA's 139-year record. The period of 2015–2017 had a global temperature departure from average that was more than 1.0 °C (1.8 °F) above the 1880–1900 average, which is a period that is commonly used to represent the pre-industrial conditions. However, 2018 was just shy of reaching the 1.0 °C (1.8 °F) mark at 0.97 °C (1.75 °F). The year began with a La Niña episode present across the tropical Pacific Ocean, transitioning to ENSO-neutral by April 2018 (NOAA 2018).

During the twenty-first century, the global land and ocean temperature from average has reached new records (2005, 2010, 2014, 2015, and 2016), with three of those being set back-to-back. Nine of the 10 warmest years (Table 22.2) have occurred since 2005, with the last five years (2014–2018) ranking as the five warmest years on record (NOAA 2018). Table 22.2 shows the warmest 10 years during 1998–2018 period.

According to the Intergovernmental Panel on Climate Change (IPCC) report, the annual average global temperature increased by about 0.74 °C during 1906–2005, and the air temperature increase over the past 25 years has been 0.2 °C per decade.

Table 22.2 Top 10 Warmest Years (1998–2018)

Rank (1 = Warmest, period:1998–2018)	Year	Anomaly (°C)	Anomaly (°F)
1	2016	0.95	1.71
2	2015	0.91	1.64
3	2017	0.85	1.53
4	2018	0.79	1.42
5	2014	0.75	1.35
6	2010	0.70	1.26
7	2013	0.67	1.21
8	2005	0.66	1.19
9	2009	0.64	1.15
9	1998	0.64	1.15

According to the 5th Evaluation Report (AR5) of IPCC published in 2014, the global temperature increase exceeded 0.85 °C (IPCC 2014).

There has been a distinctive change in the profile of carbon isotopes in the atmosphere: CO_2 produced from burning fossil fuels stands out because plants prefer the lighter of the two stable isotopes of carbon (Carbon-12 rather than Carbon-13), and the ratio of Carbon-13-Carbon-12 in the atmosphere fell in the twentieth century at the same time levels of CO_2 began to rise sharply. The climate record displays that the upper atmosphere, the stratosphere, is cooling, at the same time as warming comprises closer to the Earth. The thickening greenhouse blanket in the lower atmosphere contributes to both changes, trapping reflected heat that would otherwise radiate into space (Stocker et al. 2013).

22.2.3 *Factors Affecting World Climate*

Over time, the climate system evolves under the influence of its internal dynamics and changes in external factors affecting the climate. External factors are natural phenomena that change the structure of the atmosphere such as human-induced factors, volcanic eruptions, and changes in solar temperature. Radiation from the sun constitutes the power of the climate system.

There are three basic ways to change the world's radiation balance:

1. Changing the radiation coming from the sun
2. Changing the amount of reflected solar radiation
3. Changing the long-wave radiation sent back to space from Earth

As a result, the climate reacts directly or indirectly to such changes through various feedback mechanisms.

22.3 The Consequences of Climate Change and Its Effects on Humans

22.3.1 *Climate Change and the Role for Human Behaviors*

In 2017, the Earth's climate set alarming records for both surface, ocean temperature and sea ice extent. Recent analyses by the National Aeronautics and Space Administration (NASA) and the National Oceanic Atmospheric Administration (NOAA) displayed that 2017 ranked as either the second or third warmest year for global surface temperature on record since 1880, depending on the analysis method used (NASA 2018).

Even though evidence of global temperatures reaching a plateau from 2014–2016, in 2017, global warming has continued at an upwards trajectory. In the record of average near-surface temperatures, 16 of the 18 warmest years have came about since 2001, and the average global surface temperature has now risen about 1.1 °C above pre-industrial levels, averaged over the period 1850–1900 (Met Office 2018).

22.3.2 *Human Contributions to Warming*

Various comprehensive assessments of the climate system conclude that increasing concentrations of anthropogenic GHGs (greenhouse gas) have been the primary driver of global warming since the mid-twentieth century (IPCC 2014; UNEP 2017).

Concentrations of GHGs in Earth's atmosphere have changed throughout history, resulting in seven cycles of glacial advance and retreat in the last 650,000 years alone whereas the rapid increase in both GHG concentrations and global temperature observed today are incomparable to any rate observed over time periods ranging from decades to millennia.

22.3.3 *Effects of Climate Change on Human Life and Health*

Climate change has various effects on human health, such as malnutrition, infant mortality, hygiene, waterborne diseases, and cardiovascular diseases. Moreover, population distribution in geographic risk zones, protection of natural agricultural areas, nutrition and socioeconomic status should be taken into consideration (Çelik et al. 2008).

Increasing climate change, heat waves, increasing precipitation and rising sea level affect water, agriculture, certain diseases and human health. Migration from rural areas to cities, technology, industry, and changing land use habits accelerate climate change. Some natural disasters, hurricanes and floods that are becoming more frequent and severe due to climate change lead to large migration waves. However, possible increases in sea level may reverse this migration (Türkeş 2013).

Precipitation turning into floods due to societal risks is the result of irregular urbanization. These risks are expected to increase day by day, therefore, the first priority of Turkey within the context of climate change is to give precedence and accelerate harmonization efforts to reduce people's vulnerability. Today, the first agenda of climate change policy has been energy policy (Kurnaz 2017). After the 1960s, a sudden decrease in precipitation was observed on subtropical and tropical zones extending from Africa to Indonesia. These changes were also observed in rivers, lake levels and soil moisture. Severe droughts in the subtropical zone and especially in the Sahel region of Africa in the 1960s caused tens of thousands of people to migrate and millions of animals to die (Türkeş 1996a).

Many countries will be affected by global warming and its anticipated negative aspects such as diminishing water resources, forest fires, drought and desertification, and associated ecological degradation. Some environmental and socioeconomic impacts that may be caused by climate change due to the increase of greenhouse gas accumulations in the atmosphere can be summarized as follows (Türkeş 1994).

- Natural terrestrial ecosystems and agricultural production systems will suffer from increases in diseases and pests;
- Human pressure on sensitive mountain and valley-canyon ecosystems will increase;
- There will be new problems in water resources, especially in cities; the need for agricultural and drinking water will increase;
- Infections caused by changes in the presence/availability of water and heat stress can increase health problems, especially in large cities;

22.3.4 The Relationship Between Climate Change and Air Pollution

Air pollution is a phenomenon that endangers and harms human health, animal and plant life when substances that are not naturally present in the air are added to the composition of the air or the concentration of rare substances found in the air under normal conditions increase over normal limits (Çağatan 2011).

The increase in the number and use of motor vehicles operating with petroleum fuels, which is one of the major causes of air pollution, differs according to the characteristics of cities throughout the world. CO_2 is at the forefront in terms of air pollution and global warming. The other main problem is the prevalence of private car use in urban transport. Unless this prevalence is reduced, global warming cannot be prevented (Zorlu 2008).

With the adoption of fossil fuels as the main energy source on a global scale, a significant increase has been observed in the amount of carbon dioxide released into the atmosphere. While the amount of carbon dioxide in the atmosphere was 280 molecules (ppm/m^3) in 1850, this amount increased to 380 ppm/m^3 in 2005. In 2005, 8 billion tons of carbon dioxide gas was released into the atmosphere and the annual rate of increase of carbon dioxide emissions reached 0.5% (Denhez 2007).

Air pollution affects climate change as greenhouse gases and global warming (D'Amato et al. 2016).

When it comes to climate change, sulfur compounds reflect the sunlight back and prevent the world from overheating. It has been found that the studies and efforts on reducing air pollution since the 1970s had an increasing impact on climate change. However, the main causes of climate change and air pollution are coal, oil and natural gas used. When these fuels are no longer used, there will be no air pollution and climate change (Kurnaz, 2013).

22.3.5 Other Effects of Climate Change on Behavior

- Biodiversity will be reduced as climate change will disrupt the reproductivity of the ecological system. Parks and reserve areas are needed to reduce such problems. Changes in climate will affect the ecosystems that contribute to the production of goods and services by controlling matter and nutrient cycles, waste quality, stream regime and flow, soil erosion, air quality, and climate (Türkeş 1996c).
- Climate changes due to global warming will result especially in diminishing water resources, forest fires, drought and desertification, and associated ecological degradation. If necessary precautions against climate change are not taken, water resources will diminish in arid areas and the need for drinking water will increase, especially in urban areas (Ozturk 2002).
- Climate change will lead to changes in the natural habitats of animals and plants in agricultural activities and significant problems will emerge in terms of water resources (Soylu and Sade 2012).
- Drought caused by the decrease in precipitation has various effects on society due to the dependence of people and their activities on water resources. Long-term dry air creates a lack of moisture, leading to a reduction in plant, forest and water resources, resulting in serious environmental, economic and social problems.

22.4 Conclusion

As a result of drought, natural disasters, climate change, water pollution, environmental pollution and air pollution, migration has become an important issue in every country. Those who are engaged in agricultural activity suffer significant economic losses and turn to different professions by giving up agriculture. This leads to a decrease in production and adversely affects the investments to be made in the industry. These adverse effects will also be reflected in the national economy. People living in the country are seeking different opportunities. Governments are forced to develop new plans and programs for their countries. Migrations are increasing as a result of disasters, and this is expected to cause behavioral changes in people of different races or ethnic origins coming from different regions living in a certain place.

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Chapter 23
Role of Plant Bioactives in Sustainable Agriculture

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Abstract Plants are able to produce a number of compounds that can act as antimicrobial agent, signalling agent, phytotoxin, phytoalexin, etc. The exudates from various plant organs may contain low molecular weight compounds (including sugars, inorganic ions, vitamins, nucleotides, amino acids and phenolics), high molecular weight substances (polysaccharides and enzymes and other proteins) and root border cells (RBCs). The potent bioactive compounds that leach from the plant organs, such as seeds, stems, leaves, flowers and roots can affect the environment in a positive or negative way. For example, root exudate was observed to contribute to the complex set of chemical, physical and biological interactions in the rhizosphere, including root–root, root–nematode, and root–microbe interactions. Root–root, root–nematode and root–microbe interactions are categorized as either positive or negative. In fact, when root exudate provides nutrition to the beneficial microorganisms then the interactions are regarded as positive, while root exudate containing nematocides or antimicrobial agents that can kill nematodes or microbes the interactions are said to be negative. In short, plant exudates may consist of potent bioactive molecules that might act as a growth regulator, antimicrobial, nematicidal, and/or natural herbicide. The isolation, identification and purification of such compounds from plant sources will help in the promotion of green yet sustainable agriculture and control of pollution caused by synthetic chemicals.

23.1 Introduction

23.1.1 Plant Secondary Metabolites

The secondary metabolites from host plants may be released through various plant organs, such as roots, rhizomes, leaves, stems and seeds into the environment and affect the growth and development of other species in the rhizosphere.

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_23

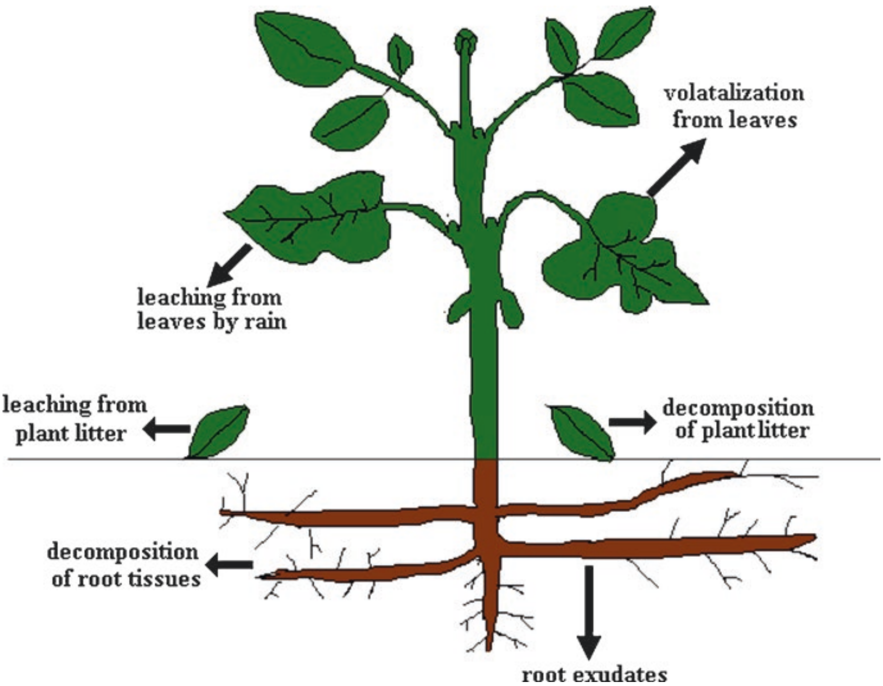

Fig. 23.1 Various routes through which plant secondary metabolites interact with the environment (Iqbal et al. 2019)

These compounds might enter the environment through leaching, volatilisation, root exudation, seed-coat exudation after imbibition and decomposition of different parts of the plant (Fig. 23.1). When susceptible plant species are exposed to the bioactive secondary metabolites, germination might be inhibited and if they germinate they might show abnormal growth and development. The most visible effects observed are retarded germination, short or no roots, lack of root hairs, abnormally long or short shoots, swollen seeds and low reproductive ability (Rice 1979).

Leaf extracts of both *Eucalyptus camadulensis* and *Juglans regia* and seed extracts of *Coronilla varia* L. contain potent secondary metabolites that can inhibit the growth and development of other plant species (Shariati 2007). Kato-Noguchi (2003b) also showed that some putative metabolites from the leaf extracts of *Pueraria thunbergiana* caused growth inhibition of *L. sativum* roots. Pisatin 1 from pea stem is another good example of vigorous biologically active compounds that inhibited the growth of *L. Sativum* at very low concentrations (Kato-Noguchi 2003a).

23.2 Agricultural Use of Bioactive Compounds

One of the most studied aspects of bioactive compounds is its role in agriculture. Much current research is focused on the effects of weeds on crops, crops on weeds, crops on micro-organisms, micro-organisms on crops, nematodes on crops and crops on crops.

The aim behind much of this research is the possible use of bioactive compounds as growth regulators and natural herbicides (a number of them are either commercially available or in the process of large-scale manufacture) to promote sustainable agriculture. A sequence in crop rotation can help in controlling weed control as the previously harvested plants may release potent bioactive compounds against weeds (Altieri et al. 2011). Phenolic compounds from the source crops can be used as herbicides and against seed borne fungi (Colpas et al. 2003). Meepagala et al. (2005) observed a high algicidal and antifungal activity of a natural compound rutacridone epoxide from *Ruta graveolens* root. Rutacridone epoxide has shown high fungicidal activity even compared with the commercially available fungicides captan and benomyl. Also, the leaf extracts from *Empetrum hermaphroditum* and *Betula pubescens* have shown potential nematocidal affect in soils rich in parasitic nematodes (Ruess et al. 1998).

23.3 Bioactive Compounds of Trees

The study of compounds that are produced by some plants to affect the environment is of great importance to understanding the mechanism of ecological interaction. Many studies have demonstrated that bioactive compounds from trees play a crucial role in forests by influencing the composition of the flora and providing an explanation for the patterns of forest regeneration. The black walnut (*Juglans nigra*) produces juglone, an a potent compound that interferes with the growth of other plant species (Davis 1928). Under natural conditions juglone enters the soil through various processes, including root exudation, litter decay and rain fall. Since root exudation is a continuous process, it is assumed that juglone is continuously added to the soil, affecting the neighboring plants (Jose and Gillespie 1998). Similarly, Davis (1928) observed that plants grown in the vicinity of black walnut died because of the presence of juglone, the physiological action of juglone was not well understood until the study conducted by Hejl et al. (1993). This study showed that juglone at a concentration of 10 μM inhibited the growth of duckweed (*Lemna minor*) by decreasing the chlorophyll content and net photosynthesis rate. The results were further confirmed by an experiment in which leaf discs of soya bean (*Glycine max*) were placed in 10 μM juglone: the rate of photosynthesis was reduced.

In North America both maize (*Zea mays*) and soya bean (*G. max*) are often planted with black walnut but had not been studied for the adverse effect of black walnut until Jose and Gillespie (1998). They studied the effect of juglone on these crops in detail. Seedlings of both species (maize and soya) were exposed to various concentrations of juglone (10^{-6} M, 10^{-5} M and 10^{-4} M) and a control (0 M). Within 3 days juglone significantly inhibited the root and shoot growth, leaf photosynthesis, transpiration, and leaf and root respiration of both species but soya was found more sensitive than maize (Jose and Gillespie 1998).

Another good example of an allelopathic tree is tree of heaven (*Ailanthus altissima*), which is native to China and was introduced in Europe around the eighteenth century. The tree of heaven is now widely distributed in the world and can thrive among a wide variety of floras, which might be due to its ability to produce several classes of allelochmicals (Shah 1997). The first investigation on the phytotoxic activity of *A. altissima* extract was that of Mergen (1959); it was confirmed by Voigt and Mergen (1962). In both studies the authors found that water extracts from foliage and stems of A. *altissima* were toxic to neighbouring plants.

A bioassay experiment to study the allelopathic effect of aqueous extract of *A. altissima* and based on seed germination and subsequent radicle growth was done by De Feo et al. (2003). The surface-sterilized seeds of radish (*Raphanus sativus*), garden cress (*Lepidium sativum*) and purslane (*Portulaca oleracea*) were incubated in Petri dishes containing filter paper, impregnated with aqueous extract from *A. altissima* or distilled water as a control. The *A. altissima* extract inhibited the root growth of radish, garden cress and purslane by 100, 80 and 72% respectively. The active compounds were isolated from the crude extract and identified as terpenoids: ailanthone, ailanthinone, chaparrine and ailanthinol B. De Feo et al. (2003) suggested that the active principle from *A. altissima* could be used as a possible natural herbicide. Phytochemical studies of *A. altissima* revealed triterpenoids (Kubota et al. 1996), lipids and fatty acids (Kcuck et al. 1994), phenolics (El-Baky et al. 2000) and volatile compounds (Mastelic and Jerkovic 2002) are the main allelopathic compounds.

23.4 Bioactive Compounds of Crops

23.4.1 Wheat

Wheat (*Triticum aestivum*), one of the essential staple food-crops, has been studied extensively for its allelopathic potential. Aqueous extracts of wheat residue (dried leaves and stem) and seedlings are autotoxic and showed an allelopathic effect against weeds (Wu et al. 2007). The inhibitory effect of an aqueous extract from wheat straw on the germination and growth of rye grass (*Lolium rigidum*) increased interest in separating and identifying the active compounds (Wu et al. 1998). The phytotoxic compounds identified in extracts were mainly phenolic acids and benzoxazinone (Wu et al. 2000).

23.4.2 Rice

Various staple crops have been screened for their weed suppressive field performances and/or laboratory allelopathic potential, with rice being the most thoroughly studied staple crop species (Belz 2007). Various classes of compounds have been identified as allelochemicals from rice exudates including phenolics, fatty acids, benzoxazinoids and terpenoids (Belz 2007). Olofsdotter et al. (2002) showed that the phenolic acid profile of allelopathic and non-allelopathic cultivars were not significantly different from each other. Further to that, the concentration of phenolics in the aqueous exudates was not enough to cause allelopathy. Seal et al. (2004) identified 15 phenolic acids in rice exudates but in very low concentrations. The non-significant effect of phenolic acids from rice on root growth of arrowhead (*Sagittaria montevidensis*) in a bioassay experiment revealed that phenolic acids were not a major class of allelopathic compounds, confirming the observations of Olofsdotter et al. (2002).

Compounds putatively responsible for growth inhibition isolated from rice root exudates were the diterpenoid, momilactone B (3,20-epoxy-3α-hydroxy-9β-primara-7,15-dien-16,6β-olide); a flavone (5,7,4′-trihydroxy-3′,5′-dimethoxyflavone); and a cyclohexenone (3-isopropyl-5-acetoxycyclohex-2-enone) (Belz 2007). Generally, different classes of allelochemicals are distributed among different tissues of rice seedling with root tissues containing large quantities of phenolic acids while momilactone B, the flavone and the cyclohexenone are abundant in both root and shoot tissues (Kong et al. 2006).

23.4.3 Barley

Barley (*Hordeum vulgare*) is a smother crop (one sown to suppress persistent weeds) that possesses allelopathic potential to inhibit weed growth (Lovett and Hoult 1995). The secondary metabolites (alkaloids: gramine and hordenine) that are released by the barley root are responsible for the inhibition of *Sinapis alba*, a weed plant. The alkaloids from barley root exudates were separated and quantified by HLPC. Hordenine was a major component of barley root exudates with a production rate of 2 μg/plant/day in hydroponic solution. Purified barley alkaloids were tested for allelopathy in a laboratory bioassay. Hordenine and gramine were applied at three different concentrations (0, 15 and 50 ppm) to surface-sterilized *Sinapis alba* seeds on filter paper and incubated in the dark for 3 days. Both hordenine and gramine inhibited radicle growth of *Sinapis alba* by increasing both size and number of vacuoles, disorganizing organelles and damaging the cell wall. The cell wall from the control treatment was uniform while cell wall from alkaloid treatment was irregular (i.e. in some part it was thinner while in other it was very thick) (Liu and Lovett 1993).

Other phytotoxic compounds were also released by barley including vanillic acid, chlorogenic acid, *p*-coumaric acid and ferulic acid. These phenolic acids significantly inhibited seed germination and radicle and shoot growth of green foxtail (*Setaria viridis*), which is a typical grass weed of arable land (Asghari and Tewari 2010). The evidence of morphological changes caused by barley allelochemicals suggests that the presence and release of those biologically active metabolites from barley may contribute to the control of weeds on arable land.

23.4.4 Rye

Natural compounds from rye (*Secale cereale*) with high allelopathic activity can also be used as a good source of natural herbicides (Burgos et al. 2004). The weed-suppressive ability of rye is due to the presence of the benzoxazinoid, 2,4-dihydroxy-1,4-benzoxazin-3-one (DIBOA) and its breakdown product, 2-benzoxazolinone (BOA) (Barnes and Putnam 1987). The effectiveness and mode of action of DIBOA and BOA on cucumber (*Cucumis sativus*) seedlings was checked by electron and light microscopy. BOA inhibited the root growth and reduced the number of lateral roots by 77–100%. DIBOA also slowed root growth but had no effect on the number of lateral roots. Both compounds reduced the regeneration of root cap cells, increased cytoplasmic vacuolation, reduced ribosome density and number of mitochondria and interfered with lipid catabolism. Disturbance in cell ultrastructure revealed that both DIBOA and BOA reduce root growth as a result of disrupting lipid metabolism, reducing protein synthesis and reducing transport or secretory capabilities because of underdeveloped dictyosomes (Burgos et al. 2004).

23.4.5 Sorghum

The allelopathic properties of sorghum have been studied for decades (Kagan et al. 2003) because of its inhibitory effect on weed growth by releasing hydrophobic compounds into the rhizosphere (Einhellig and Souza 1992). The bioactive compounds isolated from sorghum root exudates mainly consist of a dihydroquinone that was quickly oxidised to a *p*-benzoquinone known as sorgoleone (Kagan et al. 2003).

Sorgoleone when tested at 50 μM against a wide range of weeds (*Abutilon theophrasti, Datura stramonium, Amaranthus retroflexus, Setaria viridis, Digitaria sanguinalis* and *Echinochloa crusgalli*) in a nutrient medium for 10 days caused growth inhibition. The effect of 10 μM sorgoleone on weeds in a laboratory bioassay suggested that sorgoleone is a potential herbicide and contributes to sorghum allelopathy (Einhellig and Souza 1992). Further studies by Einhellig et al. (1993) showed that the stunted growth of weeds in the presence of sorgoleone is due to its interference with photosynthesis.

23.4.6 Sunflower

Sunflower (*Helianthus annuus*) has a high level of secondary metabolites that are of commercial interest. The crude extract of shoots showed an inhibitory effect on germination of lettuce (*Lactuca sativa*) seeds (Macías et al. 2007). In both greenhouse and laboratory experiments the water-soluble extract from sunflower leaf, stem, flower and root inhibited seed germination, radicle elongation, radicle weight increase, hypocotyl elongation and hypocotyl weight increase of wild barley (*Hordeum spontaneum*) (Ashrafi et al. 2008). Plant height and weight of wild barley was also reduced significantly when it was grown in soil previously used by sunflower. Incorporation of fresh sunflower roots and shoots into soil released allelopathic compounds that inhibited the germination, and the height and weight increase of barley (Ashrafi et al. 2008). Batlang and Shushu (2007) observed similar effects when they treated bambara groundnut (*Vigna subterranea*) seeds with sunflower (shoot and root) extracts on a filter paper in the dark for 5 d under laboratory conditions. Both radicle and shoot lengths were negatively affected by sunflower exudates. The water-soluble allelochemicals of sunflower could be used in weed management programmes (Ashrafi et al. 2008).

23.5 Bioactive Compounds of Other Plant Species

Vulpia myuros (silver grass), an annually growing winter grass, is one of the best examples that was extensively studied for an allelopathic effect on other plant species. An et al. (1997) started a series of experiments which provided support for the concept of *V. myuros* allelopathy. In the first set of experiments, the aqueous extracts of decomposed plant residue collected at various time-points from *V. myuros* were applied to wheat seeds. The water-soluble extract at high concentrations significantly inhibited germination while at low concentration it delayed germination of wheat seeds. The residues also showed an inhibitory effect on coleoptile and especially on growth (An et al. 1997). After that successful experiment the authors tried to purify, quantify and characterise the compounds of interest by gas chromatography – MS (GC−MS). The extracts from *V. myuros* were fractioned by gas chromatography (GC) through a wide-bore packed column. The fractions showed bioactivity towards wheat were collected and were identified by MS (An et al. 2000). In pursuit of identification they have characterised 20 active compounds, out of which syringic acid, dihydroferulic acid, vanillic acid, *p*-hydroxybenzenepropanoic acid and succinic acid were present in much higher amounts than dihydrocinnamic acid and catechol. The identified compounds accounted for 0.05% of the dry weight of *V. myuros* residues.

The identified compounds were then utilised in bioassays to test for their biological role. Each individual compound exhibited characteristic behaviour towards the test plant, wheat. Each of the compounds caused greater reduction of root elongation than coleoptile elongation. Dihydrocinnamic acid and catechol had high allelopathic effects even at very low concentrations (An et al. 2001).

Plants in the genus *Ophiopogon* are also famous for a wide variety of biologically active compounds; one of the best-studied examples is *Ophiopogon japonicus* commonly known as dwarf lily turf. *O. japonicus* was initially known for its medicinal value but was latterly discovered to be an allelopathic plant. The methanolic extract from the roots of *O. japonicus* reduced root and hypocotyl growth in lettuce.

Salicylic acid and *p*-hydroxybenzoic acid were identified as allelochemicals in *O. japonicus* by NMR (Iqbal et al. 2004).

Root exudates of buckwheat (*Fagopyrum esculentum*) are also a good source of allelopathic compounds including vanillic acid, gallic acid 4-hydroxyacetophenone. All three compounds have inhibitory effects on the growth and development of other plant species (Kalinova et al. 2007). Kushima et al. (1998) also found vanillic acid from germinating water melon seeds at a concentration of 30–300 mg/l has inhibited the shoot growth of lettuce and tomato but stimulated the shoot growth of amaranth and barnyard grass in a laboratory bioassay.

23.6 Bioactive Compounds from Plant Cell Walls

Plant cell wall polysaccharides are the most abundant organic compounds found in nature. Growing plant cell walls are predominantly composed of pectin, hemicellulose and cellulose (McNeil et al. 1984). A function of cell walls is to maintain the size and shape of the cells and ultimately plant morphology. Growing plant cells expand by the modification of existing wall polymers and addition of newly formed polymers into the cell wall architecture. This modification of the cell wall might generate oligosaccharides, some of which might influence cell and tissue growth of the host plants or act as elicitors of phytoalexins. Such oligosaccharides are known as oligosaccharins (Aldington and Fry 1994). Various oligosaccharins were prepared from plant-derived cell wall polymers.

Hemicelluloses are the second most abundant class of polysaccharides in plant cell wall. The major hemicelluloses extracted from cereals are xylans, galactoglucomannan and xyloglucan. Galactoglucomannan (GGM) is a major hemicellulose fraction of both primary and secondary cell wall of some higher plants, representing up to 15% of the cell wall dry mass. It is most commonly found in the cell walls of Leguminosae. GGM of both soft-wood and hard-wood consists of β-1,4-linked D-mannose and D-glucose with α-1,6-linked D-galactose as a side chain. It has been observed that some of the oligosaccharides derived from GGM are biologically active and are therefore oligosaccharins (Kollárová et al. 2006).

Auxtová et al. (1995) isolated galactoglucomannan from poplar (*Populus monilifera*). The GGM-derived oligosaccharides were obtained by partial acid hydrolysis. The compounds were then seperated by using gel-permeation chromatography and paper chromatography (Kubacková et al. 1992). The purified GGM oligosaccharides (GGMOs) at different concentration (10^{-5}–10^{-10} M) were then tested for their biological activity. In a laboratory bioassay several pea-stem segments were used to test the effect of GGMOs on the 2,4-D-induced elongation growth. A significant inhibition of growth was recorded after 18 h of assay. The effect was more significant at the lowest concentration tested i.e.10^{-10} M than at high concentration (10^{-5} M). In a similar experiment when Auxtová et al. (1995) added 2,4-D after 1.5 h of total 18 h experiment same result was obtained. The results from both experiments revealed that the GGMOs (DP 4–8) inhibited the 2,4-D– stimulated elongation of pea stem segments. The high inhibition at a low concentration indicated that the resulting GGMOs from GGM were not phytotoxic but were oligosaccharins.

Further biological characteristics (structure–function relationship) of GGMOs were studied by Kollárová et al. (2006). After partial hydrolysis of GGM with TFA (0.4 M), the GGMOs (DP 4–8) were obtained by GPC on Bio-Gel P-2 column. The purified GGMOs consisted of galactose, glucose and mannose in the molar ratio 1:8:33. GGMOs-g (degalactosylated oligosaccharides) and GGMOs-r (reduced oligosaccharides) produced from GGMOs with α-galactosidase and $NaBH_4$ respectively (Bilisics and Kubačková 1989) were used in the pea stem bioassay. Both GGMOs-g and GGMOs-r inhibited the elongation of pea stem segments induced by 2,4-D but the effect of GGMOs-r was higher than GGMOs-g. The result indicated that probably the galactosyl side chain linked to glucomanno core played an important role in their biological activity.

Xyloglucan (XyG) is a structural polysaccharide found mainly in the primary cell wall of higher plants. Two major types of XyG have been identified in the plant cell wall. The XXXG type consists of three repeating units of β-1,4-D-glucopyranose substituted with α-1,6-D-xylopyranose, which are separated by an un-substituted glucose residue. In type XXGG, two xylosylated glucose units are separated by two un-substituted glucose unit. To the xylose residue is bound, in addition, fucose, galactose and arabinose residues as, for example, α-L-fucopyranosyl-β-(1→2)-D-galactopyranosyl-(1→2)- and α-L-galactopyranosyle-β-(1→)2-D-galactopyranosyl-(1→2)- disaccharides (Hantus et al. 1997; Vincken et al. 1997), and smaller amounts of α-L-arabinofuranosyl-(1→2)- (Huisman et al. 2001). Xyloglucan chains bond to cellulose through hydrogen bonding and thus helps in the structural integrity of the cell wall and might play an important role in cell wall expansion (Fry 1989).

The long chain of xyloglucan can tether cellulose microfibrils, may result in a strong structure. Xyloglucan can be hydrolysed by β-1,4-D-glucanase (cellulase), releasing oligosaccharides some of which might be biologically active and regarded as oligosaccharins. Xyloglucan fragments can be obtained by enzymic hydrolysis and subsequent purification by GPC, PC and HPLC (McDougall and Fry 1994). The biological activity of purified XXFG was tested for the inhibition of 2,4-D-induced elongation of pea stem segments (McDougall and Fry 1989). Washed segments of pea were placed in Petri dishes with test material and 2,4-D (10^{-6} M). Controls were carried out without the addition of 2,4-D. XXFG showed an optimum antiauxin activity at a concentration of 10^{-9}. The same experiment was done with XXXG (lacking fucose and galactose side residues), XXLG (lacking fucose side chain) and XLFG (with an extra galactose side chain), but in all cases no antiauxin activity were observed. The results from those experiments suggested that the side chain residue (Fuc) of the XXFG is important for antiauxin activity.

The first experiment which showed the *in-vivo* production of biologically active xyloglucan-derived oligosaccharides was by (Fry 1986). The author studied the *in-vivo* formation of the bioactive nanosaccharide (XXFG) from xyloglucan by spinach cell-suspension cultures. [^{3}H]Arabinose and [^{3}H]fucose were fed to the culture.

The oligosaccharides from culture filtrate were examined by PC and GPC. One of the oligosaccharides was labelled with [^{3}H]fucose and [^{3}H]pentose residues, and was identical to XXFG. Later, McDougall and Fry (1991) fed L-[^{3}H]fucose to cell-suspension cultures of spinach. The appearance of [^{3}H]oligosaccharides and [^{3}H]polysaccharides was monitored by PC. Soluble [^{3}H]polymers were released into medium after a lag period (~30 min) while [^{3}H]XXFG was observed at an accelerating rate from ~5–8 h. From the result it was concluded that XXFG arises from the partial hydrolysis of pre-formed xyloglucan rather than by *de-novo* synthesis of oligomers.

The heptasaccharide (XXXG) and octasaccharide (XXLG) produced from xyloglucan were reduced with $NaBH_4$ to form XXXGol and XXLGol. XXLGol at a concentration of 0.5–100 nM showed a growth-promoting activity towards wheat coleoptiles in the absence of 2,4-D. In the presence of 2,4-D, XXXGol increased the auxin induced responses even at nanomolar concentration suggesting that it is a signalling molecule (Vargas-Rechia et al. 1998).

The XXFG produced from xyloglucan acts as an antiauxin in etiolated pea stems (McDougall and Fry 1989). The promoting effect on excised shoots is more pronounced when growth is already enhanced by gibberellic acid. Substitution of the XXXG core with one or two Gal residues to give XXLG and XLLG resulted in growth promotion and in-vitro stimulation of cellulase (McDougall and Fry 1991). The reduced form of XXXG and XXLG also showed growth promotion of wheat coleoptiles (Vargas-Rechia et al. 1998).

Pectins or pectic substances are a mixture of heterogeneous, branched, and highly hydrated polysaccharides composed of 17 different monosaccharides (Ridley et al. 2001). This class of heteropolysaccharides is one of the major components of plant cell wall and consists of several distinct regions (Perez et al. 2000). The 'smooth' region consists of homogalacturonan (HG) and the 'hairy' region or ramified region consists of xylogalacturonan (XGA), rhamnogalacturonan I, rhamnogalacturonan II and polysaccharides composed of mainly neutral sugars (arabinan, galactan and arabinogalactan) (Sakamoto and Sakai 1995). The composition and chemical structure of the individual segments of pectin varies significantly depending on the source from which it is extracted (Huisman et al. 2001). Unlike cellulose, pectin is largely restricted to the primary cell wall and accounts for approximately 1/3rd of primary cell wall macromolecules in dicotyledonous and non-gramineous monocotyledonous plants. Pectin plays an important role in cell wall physiology, determining the wall porosity, control of ion transport and permeability of the cell wall, regulation of cell growth and differentiation and determining the water holding capacity of the cell wall (Fishman et al. 2001). Various enzymes act on pectic polysaccharide backbones releasing oligosaccharides, some of which exhibit biological activity (Iqbal and Fry 2012; Iqbal et al. 2016, 2019; Spiro et al. 1998).

HG is a straight chain of α-1,4-D-galacturonic acid (GalA), with the carboxylic acid groups methyl-esterified at various degrees as high as 70–80% (Ishii 1997). Some oligogalacturonide fragments of HG act as bioactive molecules like hormones (Ridley et al. 2001). A mixture of oligogalacturonides produced by the action of TFA on HG was tested for their effect on development of strawberry explants *in vitro* by Miranda et al. (2007). When the mixture of oligogalacturonides was added at 0.1 and 1 mM concentration to strawberry explants it stimulated shoot and root number and root elongation. The result of high-performance anion exchange chromatography revealed that the mixture of bioactive compounds consisted of galacturonides with a degree of polymerization from 1 to 5 (Miranda et al. 2007). Similarly, a potent shoot growth promoting activity was observed in the acid extract of tomato juice waste (Suzuki et al. 2002a). Further analysis through chromatographic and electrophoretic techniques revealed a mixture of biologically active oligosaccharides (DP 2–12). The individual fractions were then utilised in a bioassay experiment. In bioassay, seeds of cockscomb on wet filter paper responded to the oligomer mixture by exhibiting growth promoting activity. The active principle was identified as an octamer of galacturonic acid ($GalA_8$). This oligomer showed stimulatory effect on shoot growth at 10 μM while at 300 μM it inhibited root growth of cockscomb (Suzuki et al. 2002b).

Rhamnogalacturonan I (RGI) is a heteropolymeric domain of pectin, consists of about 100 repeated units of [→4)-α-ᴅ-galacturonic acid-(1→2)-α-ʟ-rhamnose-(1→] in pyranose form. The C2 and /or C3 position of Gal*p*A may be substituted with an acetyl group depending on the origin of the cell wall. Polysaccharides including arabinogalactan, galactan and arabinan are often attached to the rhamnose residue of the RGI backbone at the C4 position. Arabinans are homopolymers of α-1,5-ʟ-arabinofuranose units with substitution of 1–3 arbinofuranose residues at the C2 and C3 positions. Galactan is common in various plant tissues and consists of β-1,4-ᴅ-galactose residues. Hairy regions of apple pectin also have β-1,3-ᴅ-galactosyl residues and β-1,6-ᴅ-galactose side chains. Galactan substituted with α-ʟ-arabinofuranose side chains are known as arabinogalactan I, the backbone of which is made up of β-1,4-ᴅ-galactose residues and has α-1,5-ʟ-arabinofuranose residues as a side chains. Various enzymes act on RGI including RG hydrolases, RG lyases and galactanase to produce oligosaccharides, some of which are of great interest in regard to their biological activities. In this context, Fry et al. (1993) suggested that the bioactive disaccharide (lepidimoide), which consists of rhamnose and an unsaturated uronic acid might formed by the action of RGI lyases on the RGI backbone.

RGII from pectin was found to interfere with the uptake of [^{14}C]leucine by tomato cell-suspensions (Aldington and Fry 1994). Small galacturonides (GalA and $GalA_2$), had no significant effect on uptake of [^{14}C]leucine, while $GalA_3$ and $GalA_4$ inhibited the incorporation of leucine by 25%. The authors proposed that RGII was affecting the uptake by binding the [^{14}C]leucine extracellularly and in this way preventing its contact with the cells. The unusual sugar moieties such as KDO and apiose also inhibited the uptake of [^{14}C]leucine by tomato cells but weakly. This suggested that these two unusual sugar units are integral part of RGII bioactivity. RGII also inhibited the incorporation of [^{14}C]glutamate, [^{14}C]histidine, [^{14}C]proline, [^{14}C]arginine, [^{14}C]tyrosine (Aldington and Fry 1994).

Some oligosaccharides obtained from plant cell wall degradation exhibit allelopathic effects. Zabotina et al. (2002) isolated a physiologically active compound from shoot cell walls of *Pisum sativum* after partial acid hydrolysis. The hydrolyzed fraction showed inhibiting effect on root formation in thin-cell-layer explants. The fraction mainly contained fragments of xyloglucan, galactan and arabinan with DP of 5–6.

A growth inhibitory effect has been demonstrated for xylem exudates from *Vitis vinifera* on *Lemna minor*. By ultrafiltration the crude exudate was fractioned and the inhibitory effect was observed in the 0.5–10 kDa fraction. This fraction was found to contain abscisic acid but not in a sufficient quantity to cause the observed inhibitory effect. The 0.5–10 kDa fraction was then separated on a Sephadex G-15 gel-permeation column and the fractions corresponding maltoheptaose to maltotriose were pooled together. The pooled fractions showed the same biological activity as the crude exudate, which provides evidence that the inhibitor was an oligosaccharide (Campbell et al. 1995).

The degradation product of sodium alginate formed by the action of alginate lyase (from *Alteromonas macleodii*) showed root growth-promoting activity in barley seedlings. Sterilized barley seeds were germinated in dark for 16 h; the seedlings were then placed on an agar bed containing or lacking the alginate lyase-lysate. The lysate promoted root growth 1.7-fold relative to the control within 12 d. The lysate was then fractioned by HPLC (on a CarboPac PA1 column) and each individual fraction was tested for biological activity. The compounds showing biological activity were identified by NMR as trisaccharides 4-deoxy-α-L-*erythro*-hex-4-enopyranosyluronic acid-(1→4)-α-L-gulopyranosyluronic acid-(1→4)-L-gulopyranuronic acid and 4-deoxy-α-L-*erythro*-hex-4-enopyranosyluronic acid-(1→4)-α-D-mannopyranuronic acid-(1→4)-D-mannuronic acid (Natsume et al. 1994).

A saponin with a sugar moiety extracted from whole mature *Tagetes patula* plants with methanol was observed to have a strong allelopathic effect against *Ischaemum rugosum, Vicia sativa* and *Echinochloa colona* weeds (Sondhia et al. 2005). The author isolated the saponin from *T. patula* and characterized it by NMR and MS. The authentic compound was then utilized in a laboratory bioassay. Seeds of I. *rugosum, V. sativa* and *E. colona* were incubated on filter paper in Petri dishes containing 0–10% (w/v) saponin. Both root and shoot growth was inhibited by the saponin; roots were affected most, which might be because of the direct long-term contact with the active compound.

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Chapter 24
Microbes and Environment: Global Warming Reverting the Frozen Zombies

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Abstract The earth's climate comprises of a variety of complex interactions among many components. Yet along with numerous factors, temperature is one of the most crucial factor for no life existence on other planets of the solar system. The temperature fluctuation facilitate the growth of different life forms including prokaryotes, eukaryotes and many unclassified infectious agents like viruses, prions and viroids. These organisms are playing a significant role in equilibrium of the ecosystem and their survival as well. This climate change is the result of global warming which is gradual increase in the earth's surface temperature. The increased global warming is causing the melting of glaciers and polar ice that is not only causing the increase in sea levels, but this melting is also reverting back the pathogens (FROZEN ZOMBIES) which were buried under the snow many centuries ago in the form of corpses and carcasses as a result the same infections which were once diminished from the globe are reversed back and with much more resistance. Human beings on the other hand are the most intelligent creature and having place on the top of the pyramid of ecosystem has evolved a number of tools and techniques for his survival and a healthy lifestyle by combating diseases. This chapter describes permafrost as a microbial habitat and global warming impacts on thawing of permafrost. It also covers different factors that are causing global climate changes that results in reverting back of lethal microorganisms and the infections they cause which were once vanished from the globe.

Keywords Global warming · Permafrost · Frozen Zombies · Pathogens

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_24

24.1 Introduction

The climate of earth consists of a variety of complex interactions among various components like hydrosphere (liquid part i.e. lakes and oceans), atmosphere (gaseous part), geosphere (rocks & regolith are included) etc (Schlamadinger et al. 2007). Since the creation of earth, temperature has a most important role in the origin, survival and maintenance of life on this very planet. Due to high temperature range, no life form existed initially and yet along with many other factors, temperature is one of the most imperative factors for no life existence on the other planets of the solar system. The temperature may gradually decrease from higher to lower and optimum hence different life forms including prokaryotes, eukaryotes and many unclassified infectious, agents like viruses, viroids and prions have been generated. These organisms are playing a significant role in maintenance of the equilibrium state of the ecosystem and their survival as well (Reichler et al. 2007; Schneider von Deimling et al. 2006). Being the most, superior and intelligent creature and at the top, of the pyramid of ecosystem, human has studied the ecological distributions deeply and has evolved a number of tools and techniques for his survival and a healthy lifestyle by combating diseases, development of vaccines, genetic manipulation, and many others to fulfill the growing demand of food and shelter and for the continuation of human life. But, the equilibrium between different ecological factors has been disturbed due to industrialization, deforestation, fertilizers, air-water pollutants and chemicals like chloro-florocarbons etc. This disequilibrium is in the form of climate change that remained unnoticed few years back, but at the present age, its effects cannot be kept aside or ignored (Parry and Group Ii 2007). Climate change is long-term statistical shifting of weather i.e. weather changes around the average (extreme weather events). According to a report by the European, Environment Agency, globally temperature and sea level has been increased by 0.74 °C/year since 1961, respectively. Due to the contraction of mountain glaciers, ocean water has becoming more and more acidic resulting extreme weathers events (Wu et al. 2016). Climate changes can affect the human health (Cunsolo Willox et al. 2015) in terms of infectious diseases by affecting the pathogens, their vectors and the environment in which they are found (Wu et al. 2014). This average increase in the global temperature is the result of global warming (Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). This gradual increase in temperature changes the global climatic patterns (Dhama et al. 2013b). The greenhouse gases like CO_2, N_2O and CH_4 have the ability to absorb solar radiations i.e. heat (Karl and Trenberth 2003). These greenhouse gases comprise about 1% of the atmosphere whereas the rest of the 99% are non-greenhouse gases including oxygen (O_2) and nitrogen (N_2). This greenhouse effect is responsible for the existence of life on earth as compare to other planets but increased amount of these gases in the atmosphere (due to the burning of fossils) is causing a new problem of global warming i.e. thawing of the permafrost which is threatening for the biotic and abiotic factors of the ecosystem (Treut et al. 2007). According to report of the Intergovernmental Panel on Climate Change (IPCC), there is an atmospheric increase of about 15% in methane, 31% in carbon dioxide and 17% in nitrous oxide since eighteenth century which shows that the increased emission of the greenhouse gases is directly to the increased global temperature (Venema et al. 2013). Global warming is also affecting the agriculture patterns i.e. reduction in soil salinity, which favor the emergence of different toxic bacteria e.g. *Vibrio parahaemolyticus* and ultimately leading to infectious diseases (Schets et al. 2010). The Permafrost is a frozen ground for prolong period, having a suitable physio-chemical environment for prolonged survival of life than any other habitat. It represents 26% of the terrestrial habitat and considerable number of microorganisms can survive in this habitat most of which are the most ancient viable life on the planet earth (Steven et al. 2006). Permafrost thawing as a result of anthropogenic activities expose the early life to the modern ecosystems (Rivkina et al. 2004). As a result of permafrost thawing, the vectors of the deadly infections of eighteenth and nineteenth centuries are coming back, and especially near the burial grounds where the victims of those infections were buried (Myglan and Vaganov 2005). Melting of glaciers and polar ice due to increase global warming is causing the increase in sea levels, but this melting is also reverting back the pathogens which were buried under the snow many centuries ago in the form of corpses and carcasses, as a result the same infections which were once diminished from the globe are reversed back with much more resistance. These FROZEN ZOMBIES are alarming to human and animal health. This chapter focuses permafrost as a microbial habitat and reviews microbial diversity and activities at subzero temperatures. It also reviews global warming and scientific evidences of its impacts on thawing of permafrost. It also covers different factors that are causing global climate changes that lead to melting of glaciers which results in reverting back of lethal microorganisms and the infections they cause which were once vanished from the globe.

24.2 The Permafrost

"PERMAFROST" is a term used to describe a ground that has a low temperature for at least 2 years i.e., remains at or below 0 °C (Subcommittee 1988) or a perennially frozen ground. A more suitable name suggested for this condition is "Pergelisol" and its study is called 'Cryology' (Bryan 1946). It actually represents a thermodynamic balance in earth surface temperature which is maintained by temperature of the air as well as the geothermal gradient (Steven et al. 2006). It is not at all surprising to know that most of the surface land in the northern part of the world has a temperature below 0 °C i.e. the freezing point which is not generally appreciated. Some of these vast areas consist of solid rocks and their properties are not significantly changed by thawing or freezing. However, when the surface of the ground is soil or crystalline rocks (containing water) then their characteristics are markedly affected by changing temperature below or above the freezing temperature. It is coexistent with the present climatic changes in the Arctic. It was discovered by Alexander Mackenzie and some early travelers in the north but nowadays it has become a problem. All, the problems regarding permafrost are determined, by the thermal environment of the ground. The temperature is determined by the transfer of heat to the ground which can lead to a heat gain or loss to the covering layer of the ground. This transfer makes a specific thermal environment of the ground. Certain other factors such as rainfall, wind, evaporation, sunshine and vegetation etc. can also bring changes in the thermal patterns and physical properties of the ground. In the areas where annual mean permafrost temperature is below subzero, with the upcoming summers as the environment becomes warmer so this will increase the temperature of the upper crust of the soil that will lead to thawing but only in those soils that contain water and their consistencies from being hard and solid-like will change into being wet and sloppy. The part of the soil that thaws out is called “Active layer”. The depth of this layer may vary. In Arctic it range from few decimeters to more than two meters in the Southern latitudes (Steven et al. 2006). The muskeg (nutrient poor peat land) is an excellent insulating medium and it keeps the active layer shallow (superficial). When this muskeg is removed, during digging for road building and construction purposes, the normal thermal pattern is changed and the soil that was previously prevented from thawing will be affected now. The boundary between permafrost and active layer is called “Permafrost Table” which prevents the infiltration of both layer’s surface water. Permafrost temperature ranges from 0 °C to −17 °C in Arctic and −18 °C to −27 °C in the Antarctic. Different physiological parameters have been measured from permafrost in both the polar region mentioned in (Table 24.1) (Vorobyova et al. 1997).

The Arctic sea in situ microscopic analysis shows that microorganisms are usually located in the brine veins around the ice particles (Junge et al. 2004). Water is present around the permafrost in the form of thin films that are too small to harbor the microbes however, they’re considered as a crucial element of the permafrost habitat as they provide a larger number of microbes in the *in-situ* activity, they

Table 24.1 Characteristics of permafrost soils

Location	Depth (m)	Age	Temperature (°C)	pH	Organic carbon[b]	Ice[b]	Reference
Arctic Permafrost Kolyma lowlands, Siberia.	0–100	Present to 5 M[a]	−7 to −11	5.6–7.8	0.35–10	17–164	Steven et al. (2006)
Eureka, Ellesmere Island, Canada.	0–15	Present to 20,000 years old	−10 to −17	6.5	2.19	30–100	Steven et al. (2006)
Antarctic Permafrost Dry Valley, Taylor Valley, Miers Valley.	0–17	150,000 to 2 M[a]	−18 to −27	7.8–9.8	0–0.43	Data not available	Vorobyova et al. (1997)

[a]M millions of years
[b]Percentage of dry weight soil

prevent the microbes from destruction as ice crystals are formed and they also act as "nutrient medium" for the microbial growth. These films also help in the transfer of nutrients if this transfer does not occur microbes will die due to starvation and accumulation of toxic substances (Ostroumov and Siegert 1996).

24.3 Microbial Biodiversity in Permafrost

The basic objective to study the permafrost microbiology was to learn if viable microorganisms could be isolated from permafrost or not (Cameron and Morelli 1974). The pioneering studies indicated that a significant number and variety of microbes were present in both Arctic and Antarctic environments. The isolated microorganisms included anaerobic bacteria, aerobic heterotrophs, sulfur reducing and oxidizing bacteria, and nitrogen-fixing bacteria. Most of them were psychotropic rather than psychrophilic. In addition, certain mesophiles as well as some thermophiles were also isolated. In the 1980s, the scientists began sampling by using different methods including bacterial tracers and fluid less drilling in order to ensure that the samples were in their original conditions. To identify impurities in the samples, Juck et al. (2005) introduced a two-step method including green fluorescent protein and fluorescent microspheres marked strain of *Pseudomonas sp.* during permafrost drilling for downstream culture dependent and independent analysis. This method is useful because it prevents the release of microorganisms in the environment and helps to detect the contaminated nucleic acids in the samples. A wide range of bacteria including anaerobic heterotrophs, methanogens, aerobic heterotrophs, sulfate reducers, iron reducers, nitrogen fixing and nitrifying bacteria including over 30 different genera of bacteria e.g. *Aeromonas, Bacillus, Myxococcus, Arthrobacter, Flavobacterium, Micrococcus, Rhodococcus, Pseudomonas, Streptomyces, Cellulomonas, Nitrosomonas, Nitrobacter, Nitrosospira* and *Exiguobacterium* have been reported from both Arctic and Antarctic permafrost. The direct microscopy of the permafrost has shown that the average biomass of eukaryotes as compare to prokaryotes can be 10 times higher (Vorobyova et al. 2001). A variety of anerobic and aerobic pyscrhrotrophic and pyschrophillic, spore-less and spore-forming, halophilic, halotolerant bacteria, yeast and mycelial fungi have been isolated from this environment. Microbial counts revealed ~107 cells/mL (Table 24.2) (Steven et al. 2006). Bakermans and Nealson (2004) identified 17 bacterial isolates from the cryopeg water that belonged to nine different genera including: *Bacillus, Psychrobacter, Subtercola, Arthrobacter, Microbacterium, Frigoribacterium, Paenibacillus, Erwinia* and *Rhodococcus.* Non-spore former bacteria were more tolerant to salt in comparison to the spore forming bacteria and showed a high metabolic activity at −10 °C. The ability to isolate viable cells is independent of the temperature and depends upon the age of permafrost. With an increase in age both diversity and number of isolates decreases whereas an increase in the number of sterile microorganisms observe. Absence of free liquid water causes damage to bacterial samples by the ice crystal formation that causes the

Table 24.2 Permafrost isolates growth characteristics

Isolate	Description	Minimum growth temperature[a] °C	Optimal growth temperature °C	Generation time (days)[a]	Reference
Psychrobacter cryopegella	Psychrotrophic, halotolerant aerobic Gram-negative heterotrophy	10	22	62.5	Bakermans et al. (2003)
Carnobacterium pleistocenium	Psychrotrophic Gram-positive facultative anaerobe	0	24	Not available	Pikuta et al. (2005).
Clostridium algoriphilum	Psychrophilic anaerobic spore-former	−5	5	2.1	Shcherbakova et al. (2005).
Psychrobacter sp. 273-4	Aerobic Gram-positive heterotrophy	−2.5	26	3.5	Ponder et al. (2005).
Psychrobacter sp. 215-51	Aerobic Gram-positive heterotrophy	−2.5	26	3.5	Ponder et al. (2005).
Exiguobacterium sp. 255-15	Aerobic Gram-positive heterotrophy	−2.5	42	5.5	Ponder et al. (2005).
Virgibacillus sp. Nov	Psychrotrophic spore-former, aerobic heterotroph. Capable of growth in 20% NaCl	0	30	2.4	Steven et al. (2006).
Sulfobacillus sp. Nov	Psychrotrophicfacultative autotroph. Sulfur oxidizer	−4	25	3.5	Steven et al. (2006).

[a]Generation time at which minimal growth was recorded
[b]Minimum temperature at which increased biomass was recorded

mechanical disruption of their structure. In addition, the mass transfer is also reduced in case of the pure ice samples which leads to the stoppage of inflow of the nutrients and outflow of the toxic wastes from the cells leading to cell death. Isolation of the samples from cryoenvironment has proven to be quiet challenging. Isolation and culturing permafrost microbes at *in-situ* temperatures is crucial to determine the physiological conditions and cellular mechanisms necessary for the survival of microbes in permafrost (Mackelprang et al. 2017).

24.4 Microscopic Observation of Permafrost Microorganisms

Light and electron microscopes studies of samples taken from different regions of from both Antarctic and Arctic regions have open up the existence of complete cells, partially degraded cells (cells having ruptured membranes and cell walls), ghost cells (having only cell walls) and different morphological, forms including cocci and rods. The intact cells have the characteristics of both Gram-negative and Gram-positive cell walls having capsular coatings, thick cell walls, and a non-homogenous cytoplasm that contain numerous aggregates (Soina et al. 2004). Ribosomes of cells found in closely packed condition and the nucleoid area can be seen consisting of fibril material with vesicles. The permafrost samples observed with transmission electron microscope indicated bacterial cells without ice crystals whereas in yeast cells large cavities can be seen due to probably due to the ice crystals. Cyst like forms and spore forming bacteria seem to be more common. Most specifically, microbes of size less than 1 micron are found (Soina et al. 1995). The ultra micro-forms of bacteria less than 0.41 μm in diameter makeup 80% of the permafrost population (Vorobyova et al. 2001). The microscopic observation of melted Greenland ice cores also reported the presence of very small (<1 μm), and viable "dwarf" cells suggesting the shrinkage of the size could be due to the environmental stresses (Miteva et al. 2004). Thus cells with small sizes are likely to be predominant in such environments (Steven et al. 2006).

24.5 Microbial Activity in Permafrost Environment

What could be the cold temperature limit for the microbial survival? Are permafrost active microbial entities are biologically active in situ? These above questions are the basis of studies of the cryoenvironment such as permafrost. Many bacteria isolated from the cryoenvironment although grow optimally at moderate temperature but new investigations have begun now to identify their growth patterns at a temperature below 0 °C. But due to the lack of culturing techniques, the ability to detect activity and growth at freezing temperatures is very difficult. Dating back, the minimum temperature at which the microbial activity has been shown is −12 °C for

Table 24.3 Microbial activities at freezing temperatures

Activity	Temperature °C[a]	Environment	References
Incorporation of ^{14}C-labeled acetate into lipids	−10	Arctic permafrost	Rivkina et al. (2000)
Incorporation of ^{14}C-labeled glucose	−15	Arctic permafrost	Gilichinsky et al. (2003)
Methanogenesis	−16.5	Arctic permafrost	Rivkina et al. (2004)
Sulfate reduction	−1.7	Arctic marine sediments	Knoblauch et al. (1999).
DNA synthesis	−1.5	Arctic sea ice	Smith and Clement (1990)

[a]Minimum reported temperature of detected activity

Psychromonas ingrahamii isolated from Arctic sea (Breezee et al. 2004). In detailed, examination of bacterial growth at freezing temperatures *P. cryopegella* has a maximum growth rate at low temperatures from −10 °C to 4 °C by streamlining growth processes (Bakermans and Nealson 2004). Various recent studies revealed microbial growth activities at a temperature below the freezing point of water (Table 24.3) (Steven et al. 2006). Resazurin could be used as an indicator of microbial metabolic activity but several microbial isolates are found capable of reducing resazurin at very low temperature of −10 °C but showing no cell division (Bakermans et al. 2003). *Colwellia psychrerythraea*, a bacterium isolated from Arctic sea bacterium have a minimum growth temperature of −5 °C and has an ability of motility at −10 °C (Junge et al. 2003). Microcosm radiotracer analysis and fluorescent microscopy have provided the best evidence that permafrost microbes are biologically active *in-situ*. The native microbes of the Siberian permafrost microcosm were found active at 5 °C to −20 °C to absorb 14C-labeled acetate into lipids (Rivkina et al. 2000). The rate of integration dropped at −1.5 °C, which is the ice forming temperature in the microcosm. The amount and rate of incorporation of acetate is also related to the thickness of water films in the permafrost, suggesting that a temperature below 0 °C effects microbial communities by making the liquid water less available due to ice crystals formation (Rivkina et al. 2000).

24.6 Microbial Diversity

24.6.1 Eukaryotes

The usual habitat of eukaryotic organism is snow covers and cryoconite holes which are the cylindrical holes filled with water present on ice surfaces. Surface biofilms are also present on ice sheets. Protists includes diatoms, phyto-flagellates, fungi and ciliates whereas algae including green algae and micro-invertebrates (nematodes, rotifers, tardigrades, and turbellaria), are the groups of eukaryotes found in these environments (Shain et al. 2001).

24.6.2 Prokaryotes; Bacteria and Archaea

They mostly include bacteria found in permafrost and glacial environments. These bacteria include fermenters, heterotrophs both aerobic and anaerobic, but autotrophs and lithoautotrophs specially arising from the sub-glacial environment have been drawing more attention (Hallbeck 2009). Nitrate, sulphate and iron (III) reducing bacteria are included in the anaerobic heterotrophs (Foght et al. 2004). On other hand archaea have been reported rarely in the glacial environment. Much reliable detections have been done twice in alpine glaciers and once in the melt-water lake sediments on the Ross Ice Shelf (Hodson 2006).

24.6.3 Viruses

Viruses have been reported in the cryoconite holes in the Svalbard, Norway (Sawstrom et al. 2007). The most common members of aquatic ecosystems are viruses so they are likely to be present in all the environments that carry microorganisms. These play an important role in recycling carbon and nutrients in the ecosystems that they inhabit. The presence of viruses in a specific habitat indicates the presence of living and metabolically active life forms. Since viruses being intracellular parasites require living organisms to carry out their activities, hence in some references viruses are known to be present as virus-like particles (VLP) (Hallbeck 2009).

24.7 The Glacial Environment

In glacial environments ice serves as a major source of transport. In addition, in these environments wind and liquid water also transport sediment. Wind transport happens when there is only little vegetation whereas liquid water transport will occur when the ice melt.

24.7.1 Water Availability

All forms of life require liquid water whereas in a glacier the availability of water depends on the amount of heat at given points as well as the drainage channels distribution in ice. Due to this reason, water exist as films, veins, pockets and channels at grain interstices (Paterson 1994). Physical phenomena's like air temperature and solar radiation are the controlling factors of melting ice's Heat budget. Distribution of ice at the pressure melting point is affected by the heat budgets of surface, basal, internal and thermal regimes. The pressure melting point differs among glacier and depends on the relative significance of thermal fluxes from the environments.

24.7.2 Nutrients in Glaciers

On the glacial ice and snow there is an atmospheric deposition of nitrate. A 25 years record of The National Snow and Ice Data Centre (NSIDC) reported deposition of nitrate in snow from the Amundsen-Scott South Pole station. Nitrate contents 422 and 181 ppb collected in snow sampled from depths of 0–100 cm. Sulphate from the snow and ice was also found deposited. The biogenic dimethyl sulphide of marine origin and non-eruptive volcanic emissions is the main source of sulphate (Legrand and Mayewski 1997). On other hand sulphate is found in subglacial melt water runoff and this sulphate is assumed to dissolve rock minerals. Both Antarctic and Arctic glaciers has very less amounts of phosphate and is in form of bird colonies or dust travelled, by wind (Hodson 2006).

24.8 Global Warming

Gradual increase in earth surface's temperature is called global warming (Houghton and Firor 1995). The temperature of earth has elevated to 0.3 °C–0.7 °C since 1900 and now an increase of 1.1 °C–5.8 °C have been recorded at end of twenty-first century (IP 2001). It is a change in atmospheric, temperature which influences the climatic patterns globally. A Swedish chemist Svante Arrhenius in 1896 brought up global warming concept. He discussed the greenhouse effect and describe that excess heat in atmosphere and emission of CO_2 by burning fuels would result in elevation in global temperatures (Grove 2001). Life on earth is a result of balanced interaction among atmosphere, lithosphere, cryosphere, hydrosphere and biosphere. The outermost covering of earth is atmosphere that consists of various invisible layers like mesosphere, troposphere, thermosphere and stratosphere. The most closest layer to the earth surface is troposphere and hence it actively absorbs the radiations from the earth (Polyakov et al. 2003). It is based on greenhouse gases (including CO_2, N_2O) water vapors and methane that absorb irradiation, solar radiation and hence the heat (Karl and Trenberth 2003). Solar radiations falling on the earth are absorbed by green plants and all the remaining part of these radiations is reflected back to the atmosphere (Liu et al. 2007). Atmosphere comprises of 1% greenhouse gases and 99% of other gases such as N_2 and O_2 and a constant increase in concentrations of these greenhouse gases in atmospheric region has created a new issue of global warming which adversely effects both abiotic and biotic components of biosphere (Le Treut et al. 2007). The rate of physical and chemical changes in marine ecosystem will certainly, almost dramatically speed up further in coming several years, in case of no immediate strong efforts towards minimizing climate change (Bakun et al. 2010).

24.9 Causes of Global Warming

Causes of global warming include the following two classes:

(a) Natural causes
(b) Man-made causes (anthropogenic)

Volcanic eruptions results in production of naturally large volumes of greenhouse gases. Human activities like increased CO_2 level (released from automobile), fossil fuels burning, power plants using coal fire, deforestation, farming and vast agricultural usage cause Anthropogenic global warming (Battisti and Naylor 2009). Global warming is thought to be irreversible in nature. Even if the emissions are reduced, temperatures increase would remain close to highest level (Mahmood et al. 2006). According to UN Framework Convention on Climate Dhama (2013), the organ transplantation, demographic changes and air travel are the technologic faculties among other important causative factors.

- An increased in the use of fossil fuels over a period of last 150 years leads to an increase in the production and release of CO_2 in the atmosphere. Further increase in carbon dioxide is resulted from burning fossil fuel and deforestation (Mann et al. 2003).
- In developing countries high cost, less supply and more demand of petroleum fuel has resulted in increased utilization of natural gas and coal that further leads to increased carbon dioxide emission. Sadly, increase level of carbon dioxide result in increased hurricanes' intensities (Knutson et al. 1998).
- Anthropogenic causes contribute around 30% of carbon dioxide in the atmosphere and it took about 500 years to be cleared off from atmosphere.
- In atmosphere, higher methane level results from cattle and sheep ranching, mining, decay from landfall and more cultivation.
- Population explosion is a critical factor as more people will mean more food (especially from cattle) and as a result more manure will be produced that will indirectly increase the level of increased methane concentration in atmosphere (Huesemann and Huesemann 2011).
- In nitrous oxide production, agricultural fertilizers and industrial wastes play a vital role (Aron and Patz 2001).
- Some other contributory factors towards global warming are automobile vehicles, heating appliances in homes and increase use of electricity etc. (Myrskylä et al. 2009).

24.9.1 Multidimensional Impacts of Global Warming

- Sea level rise as a result of melting of polar ice and glaciers is associated with increased global temperature. Contraction of the arctic ice cap is considered in speeding up global warming that directly affects plants, wild life and the native people (Organization 2004).
- The disturbances in weather cycle may lead to diversification of tropical and subtropical, deserts, changing intensity and frequency of weather, extremities (hottest or coldest) and cause fever, of unknown origin (Dye and Reiter 2000).
- Agricultural, yields and pattern are also affected. The emergence of toxic bacteria is favored by reduction in the salinity of soil. Increased in ocean temperature causes increase in *Vibrio parahaemolyticus* (shellfish) (Schets et al. 2010).
- Some problems like soil erosion, loss of biodiversity and degradation of the vegetation cover are associated with climate change. This degradation process is further aggravated by global warming (Thornton et al. 2006).
- Floods and droughts lead to soil degradation such as processes like grazing and cropping. Climatic change will increase salinization of soil and water. Production levels reduce in increase salinity (Masters et al. 2007).
- Dusty winds play an important role in spread of some soil pathogens (Coccidiodes) (Lederberg et al. 2003).
- Increase in rodent population is favored by increase in bushy plant that are result of increase temperature and humidity in forest (Bonnefoy et al. 2008).
- Heavy rainfall produce new breeding grounds for vectors that lead to increase insects population like flies, mites, mosquitoes, ticks and other insects that in turn influences incidences of many zoonotic and infectious diseases (Sachan and Singh 2010).
- Increased vectors population result in increased prevalence of infectious diseases such. as RMSF, Yellow fever, Dengue, Malaria and Lyme.
- Due to anthropogenic. and natural causes algal blooms increase which result in increased rate of water-borne diseases.such as water toxicity, poisoning and cryptosporidiosis (Manson-Bahr 1966).

24.10 Climate Change: An impact on Pathogens and Vectors

Infectious, diseases are becoming, worst for community due to the emerging infections in epidemic form. Such extremities lead to increase in the evolutionary potential of microbes hand in hand with their ability to be in contact with human, animal and environment. This causes the rapid occupation of new ecological niches. Gradual increase in temperature has caused diffusion of pathogenic agents and zoonotic diseases along with the enlargement of spectrum. This has a great effect on public health that ultimately result in continuous evolution of epidemiological scenarios, (Tarsitano 2011). This climatic changes as a result of global warming will modify pattern of biodiversity among pathogens and epidemiology of, infections (Lovejoy 2006).

Deforestation causes seasonal changes as well as has a great impact on transmission of zoonotic diseases Global change result in increased growth of vector/ population, increased transmission period, enhanced egg production and reduced development procedures (Dhama 2013). Increase in rainfall and temperature along with high population rate of vectors can further extend territories. of vectors to farther latitudes which cause the production of zoonotic diseases such as leptospirosis, plague and blue tongue (Rogers and Randolph 2006). High humidity levels result in increased incident of fungal diseases (such as Histoplasmosis and Cryptoccosis) and viral diseases, Ebola hemorrhagic. fever (Greer et al. 2008). Cool temperature normally limits the proliferation of malarial parasite.but warm. temperature intensify its occurrence in African territories (Russell 1998).

Climatic change like floods, storms, and droughts disturb movements of wild birds resulting in closer proximity of domestic birds to wild birds which ultimately result in increased chances of H5N1. avian influenza and Acanthamoeba infection (Dhama 2013). Increased water temperature as result of global warming also increases chances of cholera (Checkley et al. 2000). Various infections such as Hepatitis E, Cholera, Campylobacteriosis and Malaria in area of Rio de Janeiro and Philippines are caused by unusual flooding (Lipp et al. 2002). Increased temperature results in high population of cyanobacteria and algae in water bodies which cause death of marine life (Dobson 2009).

24.11 Emerging Infections

The universe is, not required to, be in perfect harmony with human ambition. For many years global climate change (GCC) remains controversial. In 1990s few countries made efforts to reduce its harmful effects, but many others. have started recently. There is powerful scientific information to explain the GCC and its direct, association to anthropogenic greenhouse gases (GHGs): CH_4, N_2O and CO_2 (Solomon 2007). The progressive aftercomes and ripple outcomes of GCC are less sure, however are probably to consist of wide impacts on emerging, diseases of animals and plants, and humans (Randolph 2009). A variety of climatic, dynamics arise, which include modifications in precipitation, ocean. chemistry, and the, frequency of intense weather events in addition to seasonal and. geographic atmosphere shifts (Stone 2008).

24.12 Examples of Emerging of Climate Change

Since 1970s, maximum earth's land surface has experienced a, 0.20 °C–1.00 °C increase in average temperature. As compare to the global, temperature of Arctic regions have, increased at nearly twice rate. About 80% of the total global warming is resulting in increase in oceans temperature which cause ice melting, and. thermal expansion. Other GCC- prompted adjustments encompass earlier timing. of spring, events, higher latitude migrations and higher elevation of animals and plants, saltification of fresh, water sources and accelerated algal and zooplankton stages in aquatic, ecosystems. Intense weather events (floods, droughts, terrible snowfall, heat waves) that immediately harm ecosystems and livelihoods. have grown frequently (Pachauri et al. 2014). This warming trend, result in increased concentrations of atmospheric GHGs, frequently carbon dioxide from burning of, fossil fuels. N_2O and CH_4 from fuels and natural and agriculture processes are.also principal contributors (EPA 2011). These GHG accumulations have not the only effects such as thermal actions but it also induces biological changes. For example, increased carbon dioxide levels decrease the crop growth selectively, weeds growth is increased, and lowers the function of popular herbicides (Backlund et al. 2008). Elevated atmospheric concentration of CO_2 results in acidification of oceans, which damages coral reef systems and estuary, resulting in, mass agitations of fisheries and food chains (Miller et al. 2009).

24.13 Infectious Diseases and Global Warming

Climate is a key.determinant of health. Environmental changes that occur due to the global, warming result in the occurrence of old diseases in new places or manifestation of new diseases. For driving the global emergence; an ever increasing role in renewal and redistribution of infectious diseases is played by unstable climate as well as global warming (Organization 1996). More than thirty new emerging and re-emerging diseases have been reported. in past 30 years (Bhatia and Narain 2010). Amongst them food-borne, water-borne, food poisoning, increasing water toxicities, algal blooms, vector-borne illnesses, and multi-host infectious diseases (viz. Dengue, Malaria, West Nile disease, Kyasunur forest disease and Japanese encephalitis,) are very important (Dhama 2013). Varity of factors are responsible for these new emerging diseases, some of them might be man influenced factors like density and population growth, crowding, trading and travel globalization, microbial adaptation, global climate, change, and modifications in ecosystems including lack of biodiversity and deforestation, wrong use of antibiotics in human beings helps in developing the resistance of vectors to pesticides, which lead to increased vulnerability to many kinds of different infections (Harlan and Ruddell 2011). Climate change that occurred, due to global, warming can cause an ecological spread which evolves a process that. results in genetic changes which are adjusted with the evolution of new emerging disease causing agents. Many diseases are caused due to extreme climate conditions to the public health and society (Epstein 2001). Emerging infections are severe threats to humans and it is the indication of entry of different pathogenic agents, which are very lethal, into the planet Earth which are not capable of entering till now due to the presence of ozone layer, a protective layer around the Earth's atmosphere, but. different gases which are the components of ozone layer are slowly and gradually decreasing which leads, to the evolution of different pathogenic agents (Martens 2013). Ultraviolet radiations coming from the sun may lead to adverse changes in the human. defense system therefore causing malnutrition in an individual and stress (Bhatia and Narain 2010). Increasing upward trends in climate changes and global temperature causes increase in sea level. and its surface temperature. which leads to increased incidence of many different water borne illnesses and also algal toxin related lethal infections (Bezirtzoglou et al. 2011). As a result of warmer climate, food storage, hygienic standards are effected which results in food poisoning (Patz et al. 2002). From all of the above information it is very evident that waterborne diseases are produced from conditions like heavy rain fall and flood due to microbes such as Giardia and Cryptosporidium (Table 24.4) (Curriero et al. 2001).

24.14 Natural Adaptation to Harsh Conditions

When some microbes are subjected to extreme environment, they start metabolizing at a very low rate that purely depends on nutrient level and temperature and some form spores in drought conditions that facilitate.their survival under energy deficient environment until conditions. improve somewhat, after which cell damage is repaired by its own mechanism. Spore-formers are mostly found in glacial ice (Christner et al. 2000), and microbes which are present at the depths >1500 meters are reported mostly spore-formers (Abyzov et al. 1998). About 30% of permafrost species are spores former, a percentage which is much higher than the one which is found in temperate soils (~1%) (Christner et al. 2000).

24.14.1 Starvation

Different microbes have different reactions to starvation. Some of the microbes react by developing ultramicrocells (Morita 1988); some make stress proteins like GroEL and chaperones DnaK (Kjelleberg et al. 1993) and Pex and Cst (Matin 1991); some other express the starvation genes that confer them a general resistance that is more enhanced (Matin 1991); some of them become dormant by reducing metabolism; some of them sporulate. *Clostridia, Bacillus,* and *Actinobacteria*, all of them are common in ice, to form a spore which is a tough coat.

24.14.2 Low Temperature

Some major summarized responses of microbes to the cold shock are (Cavicchioli et al. 2000):

Table 24.4 Global warming and emerging important infectious diseases/pathogens

S. No.	Disease	Cause/vector	Area at risk	References
1.	Chikungunya	Chikungunya virus, insects	Temperate climatic regions	Rezza et al. (2007)
2.	Crimean Congo haemorrhagic fever	Nairo virus, Tick	Asia, Europe, Africa	Bente et al. (2010)
3.	Dengue	Flavivirus, mosquito	Asia, Africa, Caribbean territories	Hayes et al. (2006)
4.	Filariasis/Elephantiasis	Wucheriabancrofti, mosquitos	Tropical countries	Graves et al. (2013)
5.	Leishmaniasis, Kala Azar	Leishmaniadonovani and other Leishmania spp., Sandfly Phlebotomus	Africa, tropical countries	Singh et al. (2008)
6.	Leptospirosis	Leptospira spp., Flood induced or water-borne infection	Rio de Janeiro, New Zealand, tropical countries	Verma et al. (2012)
7.	Lyme disease	B. burgdorferi, Ticks	United States	Dhama et al. (2013a)
8.	Malaria	Plasmodium spp., Mosquitos	Tropical countries	Rogers and Randolph (2000)
9.	Murray river encephalitis	Flavivirus, mosquito	Australian regions	Kramer et al. (2011)
10.	Plagues	Yersinia pestis, Rat flea	United States and others	Nakazawa et al. (2007)
11.	Rift Valley Fever	Phlebovirus (Bunya viridae), Mosquitos	Africa, Kenya, Somalia, Egypt	Bhardwaj (2013)
12.	St. Louis encephalitis	Flavivirus, mosquito	America	Kramer et al. (1997)
13.	Tick-borne encephalitis	Flavivirus/Tick	Asia, Africa, Europe	Daniel et al. (2009)
14.	West Nile Fever	Flavivirus, Mosquito	United States and others	Easterling et al. (2000)
15.	Hanta virus pulmonary syndrome	Hanta virus, rodents	United States, Central and South America	Epstein (2001)
16.	Trypanosomiasis	T. cruzei, T. brucei, Tsetse fly or Bugs	Cental America and Africa mainly	Simon et al. (2012)
17.	Yellow fever	Flavivirus, mosquito	Africa and America	Monath (1999)
18.	Rocky mountain spotted fever	R. rickettsii, Ticks	United States	Hunter (1998)

(continued)

Table 24.4 (continued)

S. No.	Disease	Cause/vector	Area at risk	References
19.	Relapsing fever, Typhus fever	B. recurrentis, B. duttoni, lice and ticks, respectively	India, Africa, China, Ethiopia	Hunter (1998)
20.	Boutonneuse fever	R. conorii, Ticks	Most parts of Africa	Parola et al. (2008)
21.	Foood poisoning	Multiple bacteria and their toxins	All over the world	Kovats et al. (2004)
22.	Campylobacter infection	Campylbacter species	Most parts of the world	Dhama et al. (2013a)
23.	Cholera	Vibrio cholera, water-borne illness	Poland, India, Hungary and Germany	Lipp et al. (2002)
24.	Cryptosporidiosis	C. parvum, water-borne	North America, Texas, Europe	Atherton et al. (1995)
25.	Estuary associated syndrome	Dinoflagellate, Pfiesteria piscicida	North Carolina	Morris (1999)
26.	Amnesic Shell fish poisoning (ASP), Red tides and neurotoxicity (NSP)	Water toxicity due to excessive toxin release by diatoms and dinoflagellates	Europe, Africa and north and south America	Hunter (1998)
27.	Respiratory illness, hepatitis, brown tides and harmful algal blooms (HAB)	Cyanobacterial algal bloom Toxicity	European countries, north Queensland, Brazil	Saker and Griffiths (2001)
28.	Schistosomiasis	Schistosoma species	China, Africa, Brazil, America	Mas-Coma et al. (2009)

- Increased amount of polyunsaturated fatty acids to counter the loss of membrane fluidity.
- Transport processes and lower rates of enzymes are countered by 2 approaches: (1) move to an environment enriched in organic substrates in order to compensate the less effective transport system and uptake; (2) by synthesizing a cold enzyme.
- To stabilize the secondary structures of nucleic acid and their inhibitory. effects on transcription, replication of DNA and mRNA translation by evolving specialized cold-active. proteins to synthesize catalytically efficient and structurally flexible, proteins.
- To counter the crystalline ice formation and, damage caused by it to cellular. structures by synthesizing antifreeze proteins to inhibit ice crystals formation in cytoplasm.
- Some microbial species are naturally resistant to frozen temperatures and their lifetime extended at freezing temperatures (Christner et al. 2000).

24.14.3 Low pH

Microbes should be able. to tolerate low pH in order to get benefit from nutrients in acidic veins. Cells have to maintain intracellular pH that is greater than ~6 for active biosynthesis. Spore-formers which cannot survive at this pH gradient differentiate and form spores, which resist acids environment and don't have any to maintain, the pH gradient. A non-spore-forming, such as *Dunaliella acidophila* use different methods including following: a positive surface charge; a positive inside transmembrane potential; a potent plasma membrane. H^+-ATPase which extrude protons, a membrane having very low, permeability for protons; protein and other biomolecules stabilization against inactivation of acid at the external surface of the membrane (Max and Clifford 2000). Because acidophiles include many different bacteria, eukaryotes, and archaea, members of all these domains are expected to be found in acidic veins.

24.14.4 Cross-Protection

After the successful response, to extreme conditions, cell becomes enable to resist all other stresses including salinity or acid or low temperature (Morita 1999). Low pH environment or even starvation can cause intracellular pH to drop and hence microbes develop defense mechanisms. For example during starvation DNA-binding protein.is produced from starved cells of E. coli that protects DNA from many different kinds of stress majorly including the acid-mediated. depurination of DNA (Choi et al. 2000).

24.15 Permafrost as a 'Carbon Bomb'

We can understand the feedbacks of ecosystem in response to climate change so that. adequate precaution can be adopted to minimize human.emissions. An increase in temperature would result in the thawing of frozen organic carbon which undergo decomposition (Schuur et al. 2013). About 10–30% increase in the emission of greenhouses gases would result in increased temperature (2 °C) which makes carbon available for primary productivity (Schaefer et al. 2011). However increase in growth period would result in increased photosynthetic duration which will ultimately add carbon in the permafrost (Koven et al. 2015). But decomposition rate of carbon as compare to the productivity is high which make the soil depleting of carbon.

24.16 Carbon Feedback on Global Warming

Due to global warming the Boreal and Arctic mundane ecosystems become sensitive (McGuire et al. 2009). These cold, regions are rich in organic carbon in form of frozen soil, litter and peat layers. According to earlier studies old carbon can be damaged due to high temperature (Knorr et al. 2005). Slow burial of soil carbon below thawed surface layers led to the development of enormous stock and this stock of carbon might become accessible for respiration in frozen soils (Tarnocai et al. 2009). Carbon have an impact on global warming by following methods: (i) control, soil carbon is resolved vertically and any other processes are not added here (ii) freeze, decomposition inhibited in seasonally frozen soil layers (iii) permafrost, carbon inclusion through vertical mixing of permafrost soil (iv) heat, transfer of microbial heat release as a result of decomposing to the soil thermal budget (Khvorostyanov et al. 2008).

24.17 Antibiotics Resistance of Permafrost Bacteria, Heat Radiations and Freezing Thawing Stress

24.17.1 Antibiotics

Presence e of microbial forms in permafrost provides a window into the features of microbial life. (Tiedje et al. 1994). Urban and industrial pollution results in spreading of resistance genes (by. plasmids and transposones) among bacterial communities. The only environment with unchanged microbial community is permafrost. According to previous study more than 3 million microbial populations of eastern Arctic were found antibiotic resistant. Sensitivity pattern in permafrost organisms was found different to the modern population and few were found more resistant to antibiotics such as bacitracin, carbenicillin, trimethoprim, novobiocin and ampicillin. However resistant strains to tetracycline, spectinomycin, neomycin, gentamicin, kanamycin and chloramphenicol have also been isolated. Analysis of resistant strains indicate presence of mobile fragments such as plasmids, transposons and integrons. Transposon *Tn5393* with streptomycin/ genes was found in streptomycin resistant bacteria from permafrost (Mindlin et al. 2005).

24.17.2 Heat Radiations

According to experimental data permafrost soils have high irradiation resistance as compare to thaw soil (Belova et al. 2006). Permafrost is an environment where microbial cells can survive for millions of years. Radiation intensities received by permafrost bacteria depends upon type of sediment. An estimation of radiation resistance in Arctic permafrost showed that is sand it is 0.23 μGyh^{-1} whereas 0.15 μGyh^{-1} in volcanic ash. It is biologically clear that subzero temperatures slow down the metabolic rates of the cells and make them less sensitive to ionizing radiations.

24.17.3 Freezing Thawing Stress

In laboratory after repetitive freezing and thawing cycles diversity and number of viable microbial cells in genetically similar permafrost samples didn't change. Instead of decrease in cell number microbial density was increased by several orders including frequent transition to subzero temperatures which result in cell death and then microbial adoptions to the changed environment. Water which formed as a result of thawing have numerous nutrients but initially these are in frozen form later on with passage of time these avaliable nutreints support heterotrophic growth. Saame data was found for cyst-like, non-sporeformer bacterial strains of Microccoccus and Arthrobacter speices (Vishnivetskaya et al. 2003).

24.18 Conclusions and Recommendations

Since beginning of earth temperature/ has a very significant role/ in the origin, maintenance and survival of life on this planet. Among other factors temperature is most crucial factor for no life form on other planets of solar system. Certain steps may be follow to reduce global warming these include:

- Reduce use of fossil fuel especially coal.
- Avoid compact fluorescent bulb and increase usage of incandescent light bulb among all sectors because these can save 150 pounds of/ CO_2/year.
- Use of fresh food materials in place of canned food also helps to reduce global warming.
- Use of reusable and biodegradable/ cloth bags.
- Reduce emission of toxic gases in atmosphere by burning of plastic or polystyrene.
- Methane emission during rice cultivation can be reduce by multiple draining of wet paddy/ field during the growing season.
- Addition of mustard and cotton seed cake in diet can reduce methane production in buffaloes.
- During mixing of ionospheres conversion of gram positive organisms into gram negative.

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Chapter 25
Extent of Climate Change in Saudi Arabia and Its Impacts on Agriculture: A Case Study from Qassim Region

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Abstract The Kingdom of Saudi Arabia (KSA) is one of the most vulnerable countries to climate change due to its geographical location with a continental climate, cold winter, hot summer, and random rainfall. This chapter focuses on the effects of climate change on soils and groundwater in valley wadi Rumah, Qassim, KSA by using remote sensing and geographic information system (GIS) techniques. Three satellite images (taken in 1972, 1990, and 2000) were acquired and analyzed to detect the changes in topography during these years. Climatic, field and previously published data were collected and analyzed to understand the changes in the agricultural system in the region over the past 30–40 years. The rainfall and average temperatures were increased while drought intervals were decreased. The length of valley increased by 6.7%, and average soil profile depth increased by 80–105 cm in the downstream, whereas, decreased by 70–30 cm in the upstream. A decrease in groundwater salinity (4.5–2.6 dS m^{-1}) and development of some subsurface diagnostic horizons (calcic and salic) changed the soil order from Entisols to Aridosols. These changes may be attributed to changes in the rainfall, temperature, and wind speed as a result of climate change since no human activities were identified in the valley pathways.

25.1 Introduction

Climate change induced by human activities is causing adverse effects on the earth's ecosystems. Efforts at the national and international levels are being made to mitigate these climate change effects. Over the past 25 years, mean global temperature has risen by 0.19 °C per decade and significant climate change is likely to occur

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_25

over the next century (Allison et al. 2009; IPCC 2007). The recent projections indicated at least 2–3 °C of warming by 2050 in many parts of the world, as well as large changes to rainfall distribution and weather shifts (NSW 2010). Projected climate change has the potential to have severe, but variable, impacts on soils, depending on the bioclimatic zone and the intrinsic vulnerability of the soils in that zone (Barthold et al. 2013; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Changes to land use and management as a result of climatic shifts will also potentially affect soil quality subsequently resulting in land degradation, soil erosion, soil structure decline, soil acidification, soil salinization, and potential changes in soil productivity (Ahmad et al. 2019). The Kingdom of Saudi Arabia (KSA) is about 2.3 million km^2 of mostly desert area located in arid conditions. The climate of Saudi Arabia is mostly characterized by hot and dry summer with cool and slightly wet winter. The groundwater is the main source of water in KSA satisfying more than 90% of its water demand. There are few studies investigating the future regional climate change and its impacts over KSA. Alkolibi (2002) studied the results of climate change predicted by the general circulation models and discussed the consequences of temperature increase and precipitation decrease on water resources and agriculture in KSA. Likewise, Meehl et al. (2007) stated that an increase of 0.1 mm/day at the end of the twenty-first century in the mean annual surface evaporation for most of KSA is expected, except for a narrow tong extending from the north towards the middle of KSA. Eheart and Tornil (1999) mentioned that the rivers basin (*valley*) located in an arid and semi-arid environment generally are the most affected areas with regard to water stress as a result of drought and high temperatures. Bruinsma (2003) summarized that agriculture production in the fragile ecosystem is responded to risks that may be caused by climate change. These risks are soil degradation and erosion, excessive extraction of groundwater, and soil and groundwater salinization.

25.2 Extent of Climate Change in Saudi Arabia: A Case Study from Qassim Region

To investigate the signs of climatic change in Saudi Arabia a preliminary assessment of systematic changes in temperature and precipitation were made based on the records of Saudi weather stations. The analysis of this data, which dates back to 1960, helped to understand the KSA situation from climate change. Furthermore, the prediction of climate change to 2050, by different models and studies carried out in KSA were gathered, analyzed, and compared to draw out general conclusions of climate change. The climatic data of Saudi weather station in Qassim were also been collected.

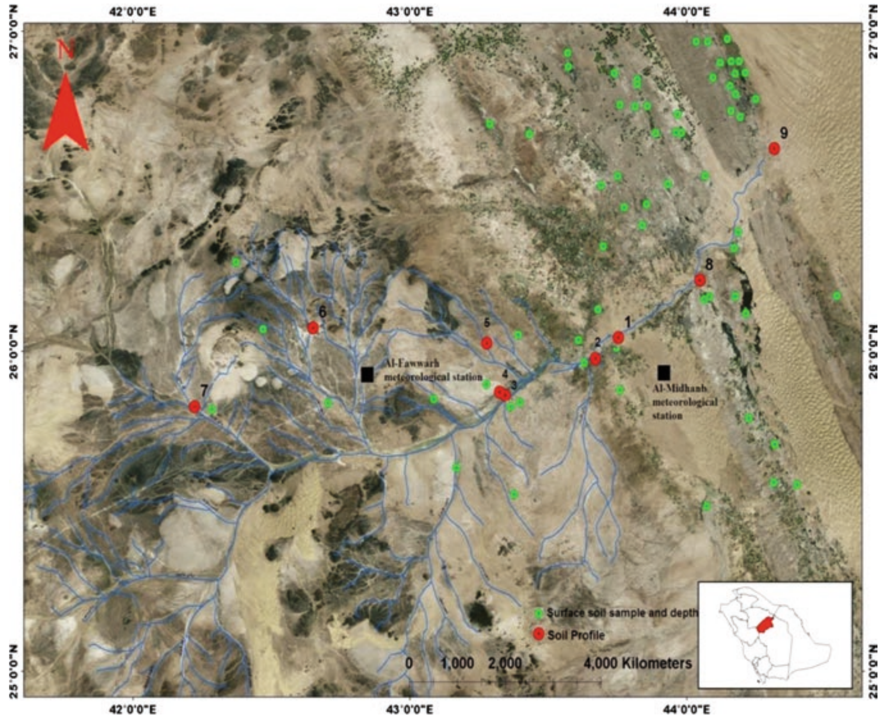


Fig. 25.1 A Satellite map for soil sampling sites and climate stations in the Qassim region

25.2.1 Climate Data Collections

Meteorological data used in this study include values of maximum and minimum temperature, rainfall, and wind speed over a period of 30 years. Those data were collected from Alumblyda, Al-Midhanb and Al-Fawwarh meteorological stations which were located in the Al-Qassim area (Fig. 25.1).

25.2.2 Climate Change Monitoring

25.2.2.1 Temperature

The data of the average minimum and maximum temperature of each year between 1980 and 2010 were acquired from Qassim meteorological stations. The data recorded during last 30 years showed that the average maximum and minimum temperature increased dramatically by about 3.3 °C (1.1 °C per decade) and 1.3 °C (0.43 °C per decade), from 31.8 to 35.1 and 17.1 to 18.4 between years 1980 and 2010, respectively (Fig. 25.2). This temperature increase is dramatically more than

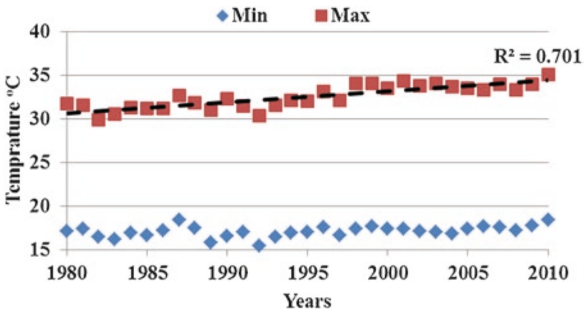


Fig. 25.2 Average temperature of Al-Qassim regions of Saudi Arabia

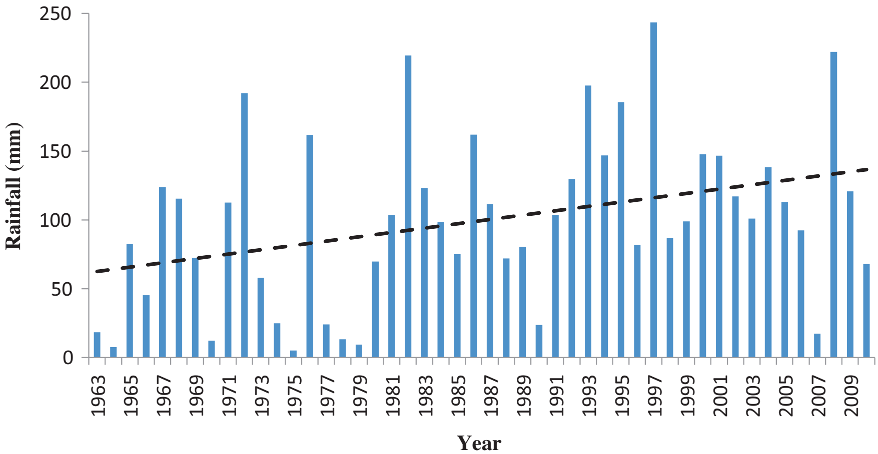


Fig. 25.3 Mean annual rainfall in Al-Qassim of Saudi Arabia

the increase recorded by Allison et al. (2009) and Hulme et al. (2002) for global and UK temperature, respectively.

25.2.2.2 Rainfall

The study of the annual rainfall of in Al-Qassim (Braidah station) during the period 1963–2010 found that the highest rainfall recorded was in 1997 (243.5 mm); on contrast, the lowest was in 1975 (5.1 mm) (Fig. 25.3). It was also observed that the drought intervals decreased in the recent three decades. The drought intervals were; 5 years between 1964 and 1970, 10 years between 1979 and 1990, and 16 years between 1990 and 2007 (Fig. 25.3). In general, the rainfall of Qassim is concentrated on winter and no rainfall recorded in summer. In this study, the tripartite moving average (TMA) was used to eliminate seasonal variation in the time series (Assani 1999; Kanohin et al. 2009). Furthermore, identical halves rainfall average (IHRA) was also used to identify the rainfall trend. The TMA is defined as the

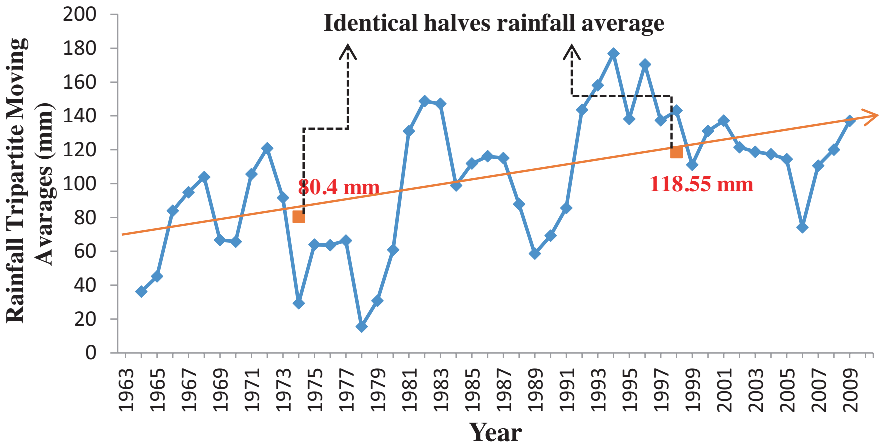


Fig. 25.4 Tripartite Moving Averages (mm) of Qassim's rainfall, Saudi Arabia

average rainfall of each successive 3 years; however, IHRA was calculated by dividing the rainfall data of time series into two equal parts, then the arithmetic mean calculated for each half part separately. By connecting the two average points in rainfall's graph, the rainfall trend line is easily extracted. Thus know whether the time series of rainfall moving toward increase or decrease. The data missionary recorded a general increase in rainfall in the studied area during time series (Fig. 25.4). These results were in agreement with those reported by Roshan and Grab (2012) and IPCC (2007).

25.2.2.3 Rain Actual Value

The actual value of rainfall considered the temperature in the calculation according to De Martonne (1923) as follow:

$$AVR = P / T$$

Where,

AVR = Rain actual value
P = Average annual rainfall (mm).
T = Average annual temperature (degrees Celsius).

Using the identical halves rainfall and temperature average, it is found that the AVR increased by 1.3, from 3.3 to 4.6 for years 1980 and 2010, respectively. On the other hand, the region climatic zone was not changed accordingly, (Arid zone).

25.2.2.4 Wind Speed

In the studied area, no wind speed change detected in the time series; however, it found mostly characterized by the incidence of moderate wind speed, 5–8.5 ms^{-1}. This wind speed is adequate for raising the sand particle to an altitude of 1000 m above the ground, and the fine soil particles up to 3000 m or more (Sharif 2014). Furthermore, the Tornado (> 11.5 ms^{-1}) was also recorded and found repeated many times each year.

25.3 Effect of Climate Change on Agriculture

The agriculture sector is known to be the most vulnerable to climate change. Contrarily, it participates in enhancing the climate change by emitting greenhouse gases (GHG) such as methane and NO_2 through the decomposition of manure, livestock rumination, and biomass burning. Therefore, the agriculture sector can play a major role in mitigating climate change by storing carbon (C) in the soil and vegetation cover.

The agriculture and food production in the KSA is expected to be affected profoundly by climate change resulting in low availability of water and reduced crop yields. Therefore, it is an urgent need of time to introduce new strategies to mitigate climate change and ensure food security in KSA. The KSA is implementing water and environment-friendly Agriculture Strategy (2010–2030) to meet the food deficiency from the global market. Moreover, strategic reserves and social security network programs will be developed to reduce market risks. Additionally, the Agriculture Strategy (AS) will help to promote Saudi agricultural investments in collaboration with other countries having high agricultural potential. The AS primarily aims to produce food and saving 8.5 billion cubic meters of irrigation water by 2030. The key targets are to (i) reduce land under wheat cultivation by 94% (from 523,000 ha in 2004 to 33,700 ha in 2030), (ii) limit the production of crops with high water consumption such as alfalfa, (iii) promote recycling the agricultural waste to develop feed industries, (iv) enhance irrigation efficiency from 45% in 2010 to 65% in 2030, (v) enhance the fish production by two folds, lifting up the fish quality up to international standards, increase fishing areas, promote aquaculture investment and improve fish resources using genetic engineering, and (vi) protect coral reefs and mangrove areas and limit erosion. A national agricultural meteorology network and early warning system will also be developed under AS to predict droughts, pests, extreme events and for water management.

25.3.1 Effect of Climate Change on Cultivated Area

The KSA widely consists of as a desert and arid climate; however, in some areas the climate has favored agriculture. The government has focused to transform a large area of the desert into arable lands through deploying irrigation projects and adopting large-scale mechanization. KSA has attained self-sufficiency in the production of dates, dairy products, eggs, fish, poultry, fruits, vegetables, and flowers and is now focused to export to the international markets. The KSA government is greatly involved in the agriculture industry and therefore formulating new agricultural policies. The government is offering long-term interest-free loans and other inputs such as water, electricity, fuel and duty-free imports of raw materials and machinery for farming. Therefore, the agricultural production of KSA has drastically improved since the last decade.

To investigate the changes in the cultivated area and its relationship to land degradation and climate change in Qassim province of KSA, we have used remote sensing (RS) techniques. The land degradation was assessed through the reduction in cultivated area from 1993–1997 to 2001–2004 and the data was linked to normalized difference vegetation index (NDVI). The % changes in both agricultural and natural green vegetation (VC%) was analyzed through a model which relates the vegetative cover to NDVI. Only a small area in the region was observed with natural vegetation and hence was ignored. Data showed that cultivated areas in Qassim in 1993 consists of 2791.19 km^2 and has been declining in 1997 and 2001. However, a minor increase of 1150.87 km^2 was observed in 2004. An uncultivated area that might be related to land degradation was estimated by vector generation (VG) for SPOT-4 (2004). The obtained data were matched with data of years 1993, 1997 and 2001. Therefore, the results of the current technique enabled us to identify the exact locations (coordinates) of the uncultivated (deserted) land in Qassim province.

25.3.2 Effect of Climate Change on Crops

Climate change and global warming have resulted in elevated temperatures consequently affecting the socio-economic conditions of a region. The elevated temperature may affect the crop yields directly as well as on the availability of irrigation water (Nelson et al. 2009). Cueto et al. (2009) reported that the temperature of the urban area in Mexicali city was increasing faster as compared to the surrounding rural area. Thus, higher urban temperatures can adversely affect energy, water consumption, and human health.

The availability of water, fertile soil and favorable climate of Qassim region help to grow grapes, oranges, lemons, grapefruits, mandarin oranges, pomegranates, and a large variety of vegetables. It has been estimated that around eight million date palm trees are present in the Qassim region. Therefore, Qassim is considered as one of the largest producers of dates in the Middle East with an annual production of 205 thousand tons of dates, giving the region a higher economic value by exporting.

25.3.3 Effect of Climate Change on Greenhouse Gas Emissions

Saudi Arabia is among the world's largest oil-producing countries. It is expected that the emissions of GHG would rise to two fold by 2030 compared to 2014 in KSA due to oil production and consumption. KSA is committed to diminishing the annual CO_2 emissions to 130 million tons by 2030, whereas, its annual emissions growth rate is 0.6%. Hence, it shows that the proposed CO_2 reduction scheme of KSA is still far from its share in global warming to keep it below 2 °C. Therefore, to cope with the problem of climate change, the KSA stance has evolved from systematic hindrance to conditional acceptance. KSA has recently signed and approved the "Paris Climate Agreement" on November 4, 2016, and King Abdulaziz City for Science and Technology Riyadh hosted a regional outreach event of Intergovernmental Panel on Climate Change in 2017.

25.3.4 Effect of Climate Change on Water Resources

The average water distribution in KSA is 98 m^3 per inhabitant per year, indicating that it is a country with severe water scarcity. It has been estimated that the total water withdrawal in KSA was 23.7 BCM in 2006 of which 98% is groundwater. Moreover, it has been estimated that 57% of groundwater in KSA is non-renewable. About 88% of the total withdrawn water is being utilized in agriculture (FAO 2008). With increasing global warming and climate change, the surface and underground water resources are decreasing significantly (PME 2005). Therefore, to cope with the situation, assessment of water resources availability, construction of 302 dams (total capacity of 1354 MCM), development of 30 desalination plants to fulfil 50% of domestic water need, promotion of wastewater utilization, water conservation regulations, and designing water saving policies in agriculture have been done in KSA (MOA 2009). Moreover, the policies for the preservation of non-renewable aquifers with limited use to drinking and prohibited use for agriculture purposes, construction of 74 dams to enhance the total storage capacity of 1349 MCB, collection and reuse of wastewater, and water conservation measures in agriculture are being implemented (MWE 2010).

Keeping in mind all the aforementioned facts, we investigated the effects of climate change on water resources in Qassim province KSA. About 49 grids (2.5° Latitude × 3.75° Longitude) covering a large area of KSA (Latitude: 16.5° N–32.5° N; Longitude: 33.75° E–56.25° E) were selected for the estimations. The variations in precipitation, temperature, relative humidity, and wind speed were recorded and analyzed. The solar radiation monitoring stations were used to estimate the net solar radiation. The changes in reference evapotranspiration (ETo) were estimated using the Penman-Monteith approach.

The results revealed that the averages ETo was 0.245 and 0.368 m/year (0.343 and 0.394 m/year in the year 2011 and 2050, respectively). It was observed that the rates of ETo were higher in the Southern part compared with the Northern part. The difference between ETo and precipitation suggested a loss of soil moisture by 0.181 m/year (0.042–0.236 m/year) during the period of 2011 through 2050. It was noticed that the increase in temperature was in the range of 1.8–4.1 °C, suggesting an increase in agricultural water demand by 5–15% to attain the same agricultural production. Therefore, the results of this study anticipated significant reductions in water sources, which may impose further stress on agriculture and drinking water sources. Moreover, the deterioration of source water quality is also expected. Thus, it is a devastating need of time formulate and implement appropriate measures for water resources protection in KSA under rapidly changing climate (Chowdhury and Al-Zahrani 2013).

25.3.5 Impact of Climate Change on Topography

Wadi El-Rumah valley is considered one of the most important geomorphologic phenomena in the Najed plateau, and is the longest valleys of the Arabian Peninsula, it receives watercourses that transect Najad plateau, which is located above the Arabian Shield through a dense network of tributaries. The valley reflects previous rainy climatic conditions where there was a great river that runs from the east of the city of Medina to Shatt Al-Arab and its length reaches up to 1200 km, In the present time and after long periods of drought it was separated from Al-Ajradi and al-Batin and became independents a result of encroaching by Althwairat and Al-Dahna sands.

Three satellite images of the region that were taken in the years 1972, 1990, and 2000 were acquired and analyzed to detect the changes in topography during the three decades. A prominent increase of 6.7% in the length of wadi El-Rumah was observed. In 1972, the wadi was 305 km long that increased to 327 km in 2000. This may be attributed to the formation of flood plains as a consequence of increased rainfall in the region. The analysis of the three satellite images also showed a slight increase in the agricultural area during this period of time.

25.4 Soil and Water Responses to Climate Change in the Arid Environment

25.4.1 Impact of Climate Change on Soil Characteristics

Three satellite images of the region that were taken in the years 1972, 1990, and 2000 were acquired and analyzed to detect the changes in topography during these years. The main changes detected were that the increase in wadi El-Rumah length by about 6.7%. The length of the wadi was 305 km earlier, which increased to 327 km currently. This may be due to the floods increase with increasing rainfall. The analysis of the three satellite images showed a slight increase in the agriculture area during this period of time.

The three-decade change detection of al-Qassim's soil properties was investigated and presented in this study. The Mashhady et al. (1986) data of Qassim's soil salinity, texture, and depth were collected and compared with the recent data. During the recent investigation, the studied locations were selected to match those used by Mashhaby et al. (1986). Furthermore, GPS and GIS techniques were used to facilitate the achievement of locations and results discussion.

25.4.1.1 Soil Salinity

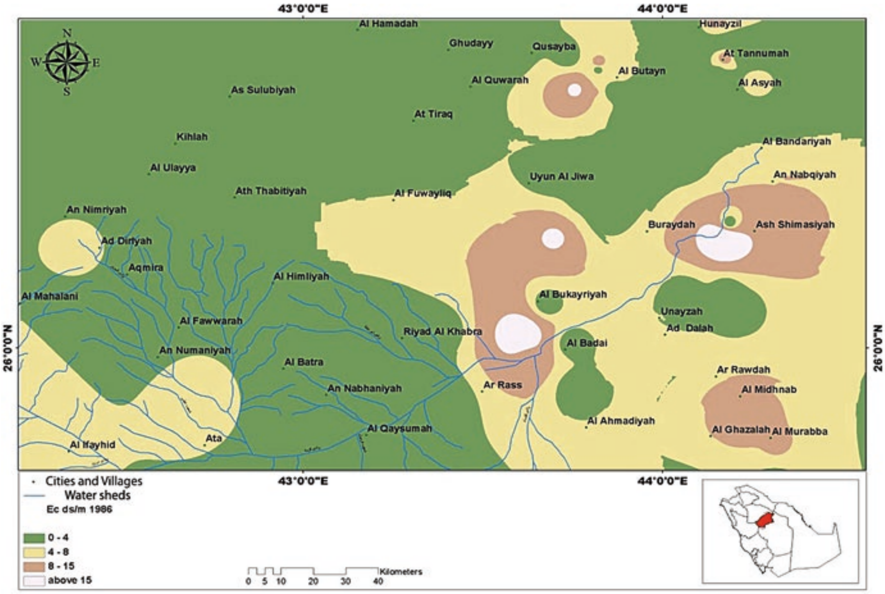
Soil degradation caused by salinization is generally referred to as secondary (or induced) salinity. This can be defined as the accumulation of free salts in part of the landscape, resulting in degradation of vegetation, water, or soil resources (Charman and Wooldridge 2007). Dryland salinization is generally a result of saline water discharge associated with high temperature. Soils play a major role in the processes of salinization. The basic soil properties of texture, soil-water-holding capacity, and soil depth, in combination with landform, will determine water flows into the surface soil.

The major changes detected in the surface of studied soils were the increase of overall soil salinity. In 1986, 60.5% of Qassim's soils were characterized by low salt content (ECe < 4 dS/m), 31.3% characterized by high salt content (ECe ranged between 4 and 8 dS/m), and the remaining were considered very high in its salinity (ECe >8 dS/m) (Table 25.1, Maps 25.1 and 25.2). In 2013, the Qassim's soils were deteriorated dramatically due to its salinity hence 47.1% of soils were characterized by high salinity and the ECe ranged between 4 and 8 dS/m; whereas, the soil of ECe < 4 dS/m represented only 44.1%. The remaining soils were classified as very high saline soil (ECe > 8 dS/m) (Table 25.1, Maps 25.1 and 25.2).

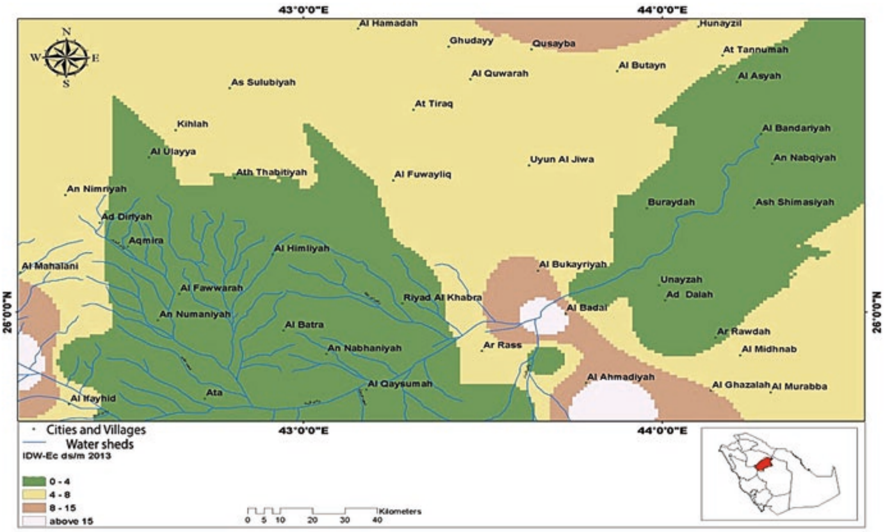
By comparing the Mashhady et al. (1986) and recent 2013 results, it was found that the in recent year, the soil salinity of class 0–4 dS/m decreased by about 16.4%; on the other hand, the soil of classes 4–8 dS/m increased by about 15.8% (Table 25.1, Maps 25.1 and 25.2). This may be due to agriculture activities coupled with climate

Table 25.1 Areas of soil salinity classes for 1986 and 2013

	Area (km)		% of the total area	
Salinity class (EC (dS/m))	1986	2013	1986	2013
0–4	20786.93	15174.7	60.5	44.1
4–8	10759.9	16207.2	31.3	47.1
8–16	2539.17	2365.9	7.4	6.9
16 >	285.2	647.7	0.8	1.9
Total	34371.2	34395.5	100.0	100.0



Map 25.1 Soil salinity of Qassim (Mashhady et al. 1986)



Map 25.2 Soil salinity of Qassim (2013)

change conditions, higher temperature and the amount and regime of precipitation, which led to high evapotranspiration and capillary flux into the surface, and then secondary salination (Fig. 25.2) (FAO 2003; Pankova and Konyushkova 2013). Interestingly, the salinity of Wadi Al-Rummah downstream soil decreased to be less than 4 dS/m in 2013; however, in 1986 the soil salinity was ranged between 4 and 15 dS/m (Map 25.1). This is expected since the rainfalls and floods in wadi have been increased in the last few decades, causing leaching of salts (Map 25.2).

25.4.1.2 Soil Depth

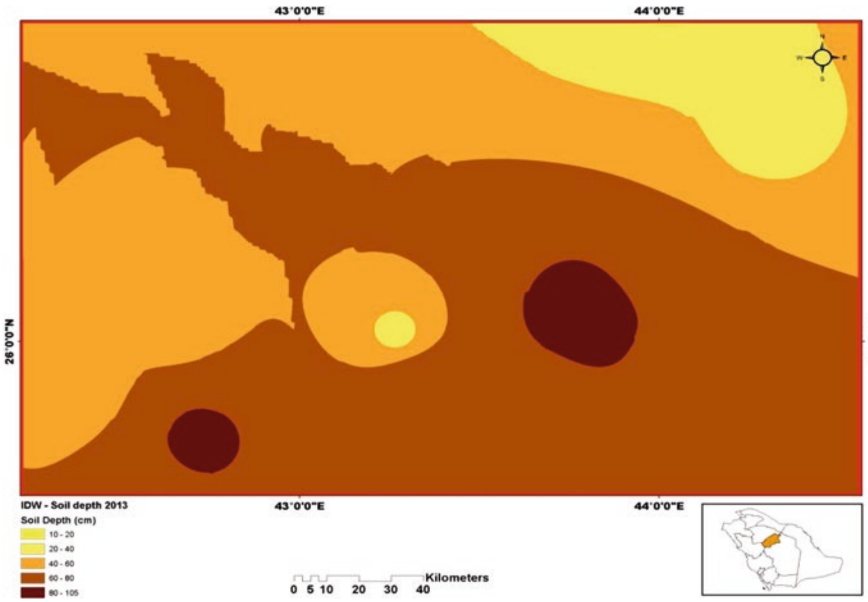
In general, the studied area is characterized by moderately soil depth. More than 50% of the studied area has a depth of soil ranged between 60 and 80 cm (Table 25.2, Map 25.3). The comparative analysis of soil depth of nine soil profiles of Mashhady et al. (1986) and recent study recorded that the soil profiles depth located in wadi upstream decreased in mean depth from 70 to 30 cm (profile no 6 and 7); on the other hand, the profiles no. 8 and 9, which located in wadi downstream increased in its mean depth from 80 to 105 cm. This is may be due to the water erosion problem in upstream and sedimentation in downstream under conditions of rainfall increase (Gupta and Chakrapani 2007).

25.4.1.3 Soil Classification

Nine soil profiles were dug and matched with investigated sites of Mashhady et al. (1986). Each profile was investigated and classified using Soil Survey Staff (2010). The result of laboratory analyzes and morphological description of the soil profile showed that the region is comprising two different soil classes; Entisols and Aridisols, the classes of dry soil. Comparing soil this classification with the study of Mashhady et al. (1986) concluded that the profiles 1, 5, 8 and 9 are similar to those of Mashhady soils. Whereas, the other profiles, 2, 4, and 7, differed in classification. The Profile 2 in 1986 had been classified Typic Torrifluvent (Entisol); however, it was classified Calic Haplosalids (Aridisols) in 2013. This is due to the development of some diagnostic horizons such as calcic and salic horizons as results of subsurface calcium carbonate and salts accumulation. These soil formation

Table 25.2 The soil depth of Qassim

	2013	
Soil depth (cm)	Area (km)	% of the total area
10–20	18.4	0.05
20–40	2973.1	8.67
40–60	12857.5	37.52
60–80	17345.3	50.61
80–105	1078.7	3.15
Total	34273.0	100.00



Map 25.3 Qassim soil depth distributions

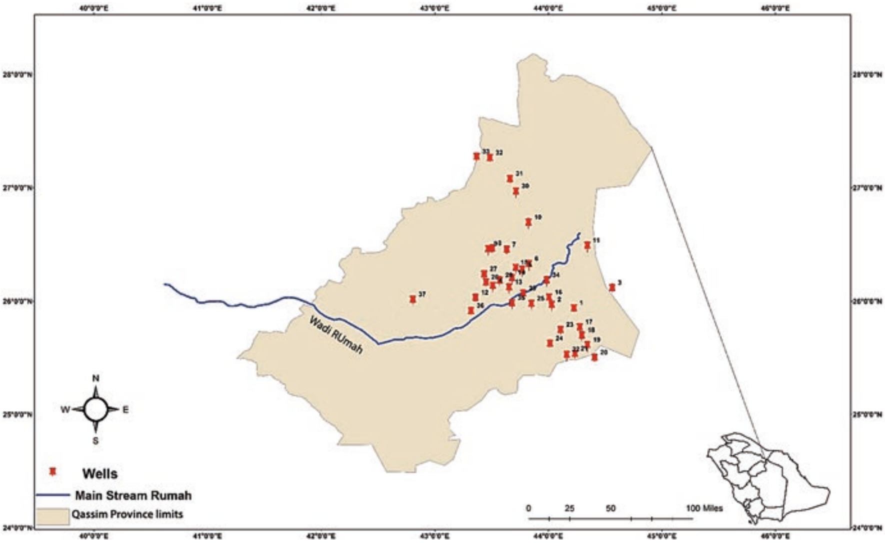
Table 25.3 Monitoring of soil classification change between 1986 and 2013

	Soil classification	
Profile no	1986	2013
1	Entisol (Typic Torriorthents)	Entisol (Typic Torriorthents)
2	Entisol (Typic Torrifluvents)	Aridisols (Calic Haplosalids)
3	–	Aridisols (Typic Haplocalcids)
4	Entisol (Typic Torrifuvents)	Aridisols (Typic Haplosalids)
5	Entisol (Typic Torriorthent)	Entisol (Lithic Torrifluvents)
6	–	Entisol (Lithic Torrifluvents)
7	Entisol (Typic Torrifluvents)	Aridisols (Typic Haplosalids)
8	Entisol (Typic Torriorthents)	Entisol (Typic Torriorthents)
9	Entisol (Typic Torrifluvents)	Entisol (Typic Torrifluvents)

processes were enhanced by humidity and drought companion coupled with climate change in the studied area (Table 25.3) (FAO 2003; Driessen and van der Linden 1970; Dudal 1990).

25.4.2 *Irrigation Water as an Indicator of Climate Change*

About 37 samples from various water wells were collected from different areas of Qassim, where the wells used for date palm irrigation and other crops (Map 25.4).



Map 25.4 Groundwater wells in Qassim area

Table 25.4 Characteristics of chemical analysis of well water samples collected from the study area

Sample	pH	EC	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			
		dS m^{-1}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SO_4^{2-}
Min	7.04	0.59	2.27	1.00	1.11	0.09	1.50	0.92	0.00	2.02
Max	7.90	16.40	66.00	21.00	74.50	2.06	70.83	12.25	0.00	89.51
Averg.	7.48	2.64	10.01	4.63	11.15	0.33	11.15	2.76	0.00	12.21
VAR	0.04	9.21	186.29	17.47	180.80	0.17	236.18	4.22	0.00	322.69
Stde. V	0.20	3.04	13.65	4.18	13.45	0.41	15.37	2.05	0.00	17.96
Cv (%)	2.69	114.86	136.29	90.30	120.59	124.77	137.78	74.56	0.00	147.08

Min Minimum, *Max* Maximum, *Averg.* Average, *VAR* variance, *Stde.v* standard division, *CV* variation coefficient

The water samples were characterized (Table 25.4) and various water quality indicators for irrigation were calculated (Table 25.5). The study conducted by Al-Modhish et al. (2009) in addition to the current study was used to show the effect of climate change on well water available in the study area. Geographic information systems were used to produce the maps of some of the water characteristics to assist in the comparison and to show the impact if any.

The results revealed that the pH values of the studied samples ranged from 7.0 to 7.9 with an average of 7.5 and a standard deviation of 0.20. The pH of all the samples was seen within the expected water limits used in irrigation according to the FAO classification (Ayers and Westcot 1994). The average value of electrical conductivity was 3.0 dS m^{-1} with a range of 0.59 and 16.4 dS m^{-1}, and a standard

Table 25.5 Irrigation water quality indicators calculated for wells in the study area

Sample no.	pH	EC (dS m^{-1})	SAR	SAR_{adj}	Adj. R_{Na}	SSP (%)	ESP (%)	RSC me/l	PS mg/l
Min	7.04	0.59	0.72	2.15	0.79	24.25	−0.20	−85.10	2.51
Max	7.90	16.40	11.92	49.70	15.41	58.05	14.03	−2.07	115.01
Averg.	7.48	2.64	4.03	15.22	4.57	39.29	4.35	−11.89	17.26
VAR	0.04	9.21	6.68	127.17	10.68	71.82	10.89	310.64	472.42
Stde. V	0.20	3.04	2.59	11.28	3.27	8.47	3.30	17.63	21.74
Cv (%)	2.69	114.86	64.20	74.11	71.48	21.57	75.79	−148.26	125.92

EC_{iw} Electrical conductivity, *SAR* Sodium Adsorption Ratio, *SAR_{adj}*. Adj. Sodium Adsorption Ratio, *Adj.R_{Na}* Adj.Sodium Ratio, *SSP* Soluble Sodium Percentage, *SSP* Exchangeable Sodium Percentage, *RSC* Residual Sodium Carbonate, *PS* Salinity Potential

Table 25.6 The limits of the salinity of irrigation water for the classification of FAO (Ayers and Westcot 1994)

Class	Range (dS m^{-1})
Excellent	< 0.7
Good	0.7–3.0
Fair	> 3.0

deviation of 3.0, according to the FAO classification (Ayers and Westcot 1994) (Table 25.6). The concentration of salts was ranging from 0.7 to 3.0 indicating suitability for irrigation, however, 8 samples were found with a concentration of salts above 3.0. Therefore, increasing the salinity of irrigation water has a detrimental effect on the plant, especially when it increases its concentration in the root spread area and thus leads to a decrease in productivity.

The results presented in Table 25.4 showed that the sodium was the predominant cation with concentration exceeding the permissible limit in irrigation water by 9 meq L^{-1} in 11 samples of well water, while most of the samples were less than 9 meq L^{-1}. The concentrations of calcium, magnesium, and potassium were within the normal and expected concentration of groundwater used for irrigation purposes. For anions, the predominance of SO_4^{2-} in most water samples was followed by Cl^- anion that exceeded the recommended concentration in irrigation water (4 meq L^{-1}) in most samples with values ranging from 1.5 to 70.8 meq L^{-1} and means 11.2. The concentration of HCO_3^- is much lower than the critical limit (8.5 meq L^{-1}) except for a well water sample which was 12.3 meq L^{-1} (Ayers and Westcot 1994). Figure 25.5 shows the relationship between electrical conductivity (soluble salts concentration) and total dissolved ions (TDI) in mg L^{-1} unit.

The sodium values are used to give an indication of the seriousness of sodium in irrigation water because they depend on the quantitative relationship between dissolved and inert ions. This helps to determine the amount of sodium in the soil. Table 25.5 showed the values of the dissolved sodium ratio (SAR) ranging from 0.7 to 11.9 SAR and the average of 4.0, and is within the expected limits of the groundwater survey using irrigation water, except for 3 samples of well water which exceeded the limit in irrigation water (9) (Table 25.7). The use of such qualities requires good management such as good drainage, the addition of natural gypsum

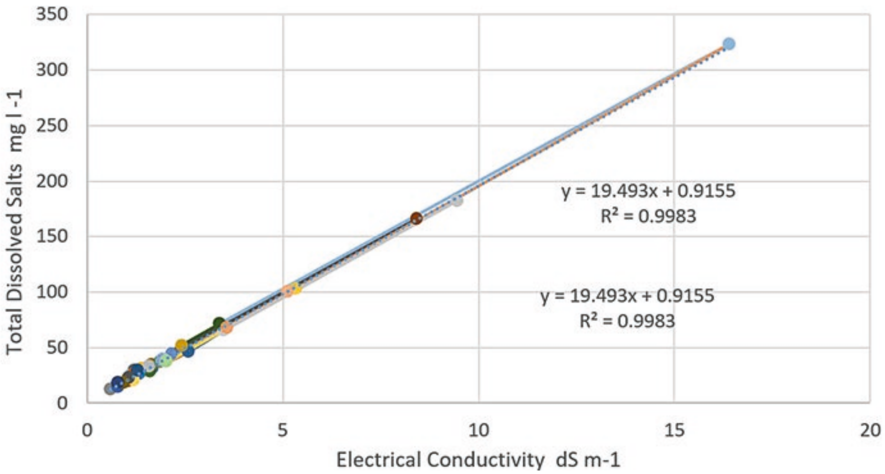


Fig. 25.5 The relationship between electrical conductivity and total dissolved ions in irrigation water in the study area

Table 25.7 The limits of the ratio of sodium adsorption in irrigation water

Class	Range
Low	< 3
Medium	9–3
High	> 9

According to the FAO classification

Table 25.8 Percentage limits of dissolved sodium in irrigation water

Class	Range
Excellent	< 20
Good	40–20
Permissible	60–40
Doubtful	80–60
Unsuitable	100–80

According to James et al. (1982)

to get rid of the high concentration of sodium, and the addition of manure to improve soil properties.

Adj. Sodium Adsorption Ratio (SAR_{adj}) ranged between 2.2 and 49.7, while the values of Adj.Sodium Ratio (Adj.R_{Na}) ranged from 0.8 to 15.4. These values indicate an increase in SAR (SAR), which is about twice the values obtained (SAR and Adj.RNa). The values of sodium exchange ratio (ESP) ranged between −0.2 and 14.0 and average 4.4%. Exchangeable Sodium Percentage (SSP) of the total irrigation water samples were relatively of high values, and their effect may be simply because they did not exceed the limit (allowed in irrigation water, Table 25.8) (James et al. 1982).

Table 25.9 The remaining sodium carbonate limits (Ayers and Westcot 1994)

Class	Range
Suitable	< 1.25
Marginal	2.5–1.25
Unsuitable	> 2.5

The Salinity Potential of irrigation water (PS) ranged from 2.5 to 115.0 and average 17.3. The salinity values for saline irrigation were between −85.1 and –1.2 and the RSC values were 3.17. The Residual Sodium Carbonate values (RSC) ranged between −85.1 and –2.1. The calculated values of the Residual Sodium Carbonate were low (Negative values). Excellent irrigation water has no effect in terms of calcium and magnesium deposition potential, Table 25.9.

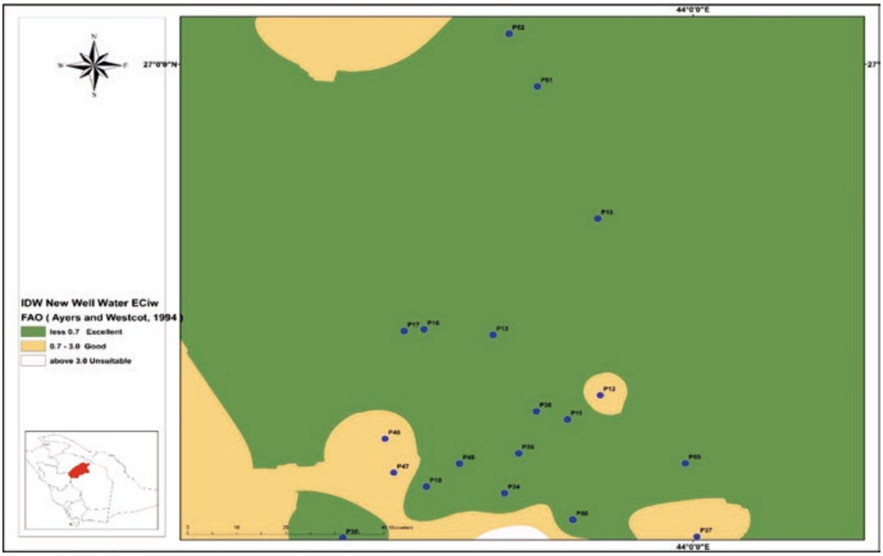
To demonstrate the effect of climate change on the characteristics and quality of irrigation water, the results of 22 well water samples from the study area were collected by Modaihsh et al. (2009). The two characteristics (ECiw and SAR) were selected for comparison. The pH values of the well water samples ranged from 7.1 to 8.7 at an average of 7.8. ECiw was high in some wells, ranging from 1.0 to 18.7 dS m^{-1}, averaging 4.5 dS m^{-1}. The ratio of sodium adsorption ranged between 2.5 and 14.6 with an average of 5.5. The rate of sodium adsorption (Adj.SAR) was between 5.1 and 51.5 and mean 13.9. The calculated sodium adsorption rate ranged from 3.1 to 18.5 with an average of 6.9.

Comparison of spatial distribution maps and salinity values for the study conducted by Al-Modhish et al. (2009) and the current study according to the FAO standard (Ayers and Westcot 1994) shows that there is a decrease in salt concentration in irrigation water in the study area in general. Salinity ratios in the general average from 4.5 dS m^{-1} in the previous study to 2.6 dS m^{-1} were reported in the present study. This is confirmed by salinity distribution maps at the time of conformity (Maps 25.5 and 25.6). This decrease in salinity may be due to an increase in annual rainfall as indicated by the average rainfall data during that period, which in turn has been slightly improved in some of its characteristics as a result of the recharge of ground reservoirs.

By comparing the spatial distribution Maps (25.7 and 25.8) and the SAR values we found that there was a decrease in the sodium values of the current study compared to the previous study. The SAR values ranged between 0.7 and 11.9 and average of 4.0, 2.5, 14.6 and 5.5 respectively. We concluded from this lack of impact and severity of sodium.

25.5 Saudi Arabia's Future Vision on Climate Change

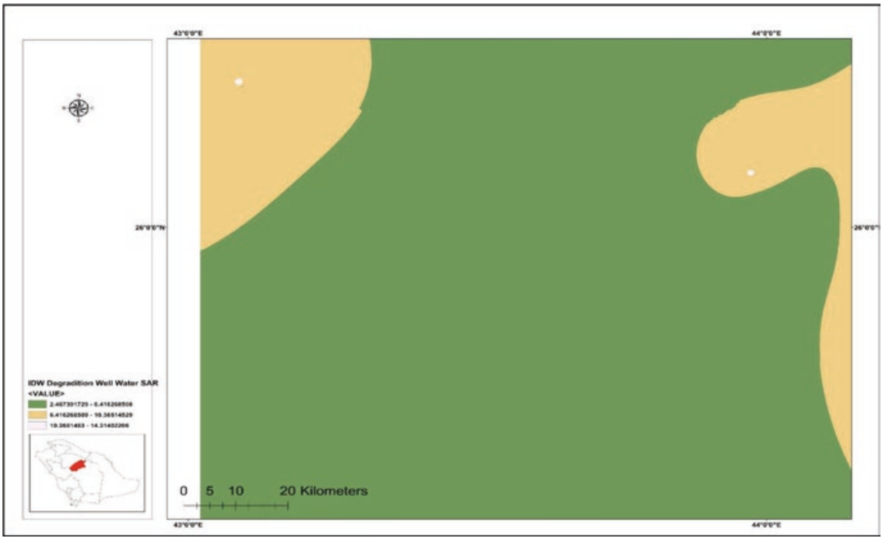
It has been found that climate change has influenced all the aspects of life in the KSA, including health, water resources, fisheries, biodiversity, food, agricultural production and forest, and rangelands. Therefore, the government, private sector, civil society, and science and technology institutions need to work together to solve



Map 25.5 Spatial distribution of the concentration of salts dissolved in irrigation water for the current study 2013

Map 25.6 Spatial distribution of soluble salts concentration for the study of Modaihsh et al. (2009)

Map 25.7 Spatial distribution of sodium adsorption for the current study



Map 25.8 Spatial distribution of sodium adsorption ratio for the study of Modaihsh et al. (2009)

the climate change problem. Considering this situation, the KSA Government approved the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and the Kyoto Protocol in 2005. Moreover, KSA joined Carbon Sequestration and Leadership Forum (CSLF) as well. Various C capture and storage (CCS) initiatives have been taken and several Clean Development Mechanism (CDM) workshops have been hosted recently in KSA. The first national communication was submitted in 2005 and the second was submitted in 2010.

25.5.1 Impacts of Response Measures on the Saudi Arabian Economy

The KSA consists of semiarid to hyper-arid climate with very low rainfall (annual average of 70.5 mm) and extremely high temperature. The extreme weather conditions are responsible for water scarcity and reduced vegetation cover. It has been estimated that around 2% of the land area in KSA is arable with dates and fruits as major crops. Additionally, KSA is among the biggest oil and gas producers in the world. These circumstances have led to huge emissions of GHG gases consequently resulting in global warming and climate change.

The estimated CO_2 emissions from 1990 (first national communication) to 2005 (UNFCCC) were 140,958 Gg. Statistics revealed that the energy sector contributes to 90% of CO_2 emissions, industrial sector contributes to 8% and agriculture contributes to 2%. The temperature in all over the KSA has increased from 0.15 to 0.75 °C, with an average of 0.40 °C (PME 2005). This warming pattern showed the systematic distribution and higher warming in the middle part of KSA, while lower warming along the western and eastern coasts. All the northern parts and eastern slopes of the Asir mountains of KSA exhibited lower precipitation (as low as −40% and −14%, respectively). The GCM models predictions showed that the average warming in KSA during summer would be higher (2.2–2.7 °C) than global average warming by 2041. These results showed that the lowest warming (0.2–0.4 °C) would be in the south and the southwest. Likewise, IAP_97 model prediction showed that the annual rainfall will increase with moisture ranging 20–30% in the southwestern parts (Sarawat Response to Climate Change in the Kingdom of Saudi Arabia – El M. Darfaoui and A. Al Assiri 2 Mountains), while it will decrease (7–18%) in other parts of the KSA except for the Makkah and Madinah regions. It has been estimated that coastal areas will grow about 1% per year with a rise in sea level and will result in loss of 401–1726 hectares of sandy beaches along Arabian Gulf and 1087–4674 hectares of sandy beaches along the red sea by 2100. Therefore, due to the fact that major part of the ecosystem in KSA is sensitive, water resources are scarce, fossil fuel dependent economy, and higher demographic pressures (2.3%), the KSA is very vulnerable to the climate change. Thus, various mitigation and adaptation measures are being taken to evade the adversities of climate change; nevertheless, there is a lot to do more to mitigate this global and national challenge.

25.6 Conclusion

Agricultural productivity is extremely vulnerable to climate change globally in general and arid to semi-arid regions in particular. The rapid increase in climate change and global warming is posing a serious threat to environment, agriculture and food security. Climate change could be more hazardous in KSA in the future due to the harsh climate, temperature extremes, and rainfall changes. Therefore, developing and adaptation strategies through climate and crop growth models to counter the adverse impacts of climate change on farmers and community is an urgent need of time. Rise in temperature due to climate change could affect the type of crops and cropping seasons. Taking Qassim province of KSA as an example, it was found that the average maximum and minimum temperatures increased dramatically by about 1.1 and 0.43 °C per decade, respectively. Moreover, it was found that the rainfall was increased, drought intervals were reduced and moderate Tornado occurred during the last three decades. Thus, the soil quality has been reduced, soil salinity increased and soil depth decreased especially in downstream during the last three decades due to climate change. Consequently, the humidity and drought coupled with climate change has affected the soil formation processes and resulted in the development of some subsurface diagnostic horizons such as calcic and salic due to calcium carbonate and salts accumulations.

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Chapter 26
Rice Production Under Climate Change: Adaptations and Mitigating Strategies

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Abstract In the current scenario of global climate change, the utmost desire to ensure food security is to maintain and increase agricultural production. But, due to rapid climate change, many abiotic factors such as rainfall, drought, flooding, temperature and solar radiations are severely affecting the production of rice at various growth stages. It is predicted that almost 51% of rice cultivation and production would be reduced during the next century due to global climate change. However, agriculture activities are also contributing to global warming by 10–14% of total global greenhouse gas emissions and 18% of the total methane is emitted from paddy rice fields. Therefore, mitigating and adaptation strategies such as alternate wetting and drying, inter cropping with short term vegetation, limiting chemical fertilizers by precise farming, usage of rice cultivars with low methane emission, improved tillage, recycling of farm waste into organic fertilizers, and by developing integrated rice farming system, are needed to hinder greenhouse gas emissions from rice fields. Furthermore, strategies are required to cope with effects of climate change on rice production by application of anaerobic methanotrops to oxidize the CH_4, and the development of high-yielding and abiotic stresses-tolerant (temperature, drought) and resistance rice cultivars by using different new breeding, genetic engineering and genomic tools. Besides that, other management options such as development of weather-proofed farm equipment, shifting of planting and adjustments in cropping dates and use of climate forecasting by using remote sensing and modeling can also be used to sought out the climatic issues.

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S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_26

Keywords Climate change · Global warming · Paddy · Methane (CH_4) · Methanotrops

26.1 Introduction

In the twenty-first century, rapid change in global climate is a serious concern worldwide. According to the fourth report of IPPC 2007, global temperature has raised by 0.6 °C to 0.8 °C during the last century which is the most remarkable increase in global temperature over the last 1000 years (Lu et al. 2019). Climate change has a strong association with agriculture production and 20% greenhouse gases (GHGs) emission caused by agriculture (Hutsch 2001; FAO 2009; Shakoor et al. 2018). Food security has been susceptible by different factors, and it is expected to face new challenges in near future (Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017). Researchers of modern era and policymakers are evaluating the impact of climate change on agricultural production in order to ensure food security (Dabi and Khanna 2018). Many factors are responsible for climate change and posing a negative impact on crops especially rice such as temperature variability, salt stress, water scarcity (drought), heavy rains, floods, and melting of glaciers.

The fast-growing global population needs a larger food supply (Petersen 2019). According to an estimate, a 100–110% increase in crop yield and production is needed in order to feed whole population by 2050 (Kontgis et al. 2019). The world's climate is changing rapidly, and it has a significant impact on agricultural production by increasing carbon dioxide (CO_2) regimes, global temperature, and unpredictable changes in rainfall pattern. Such as, the intensity and frequency of extreme heat is expected to increase, which could harm overall food systems (Battisti and Naylor 2009; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). While C_3 agricultural crops for example rice, soybean, and wheat may get benefit from rising levels of CO_2 regimes, however it is not clear yet whether the possible potential benefits will outweigh the harmful impacts from increasing temperatures (Schmidhuber and Tubiello 2007; Kontgis et al. 2019). Both floods and droughts are also predicted to increase the intensity and frequency of global temperature in the next few decades because of climate change, which is directly responsible to decrease the crop yields. Crop yield and growth is strongly associated with weather conditions (Petersen 2019). Worldwide, more than 50% variability in crop yield observed only due to climate variation (Ray et al. 2015), particularly high temperature during critical stages of the crop growing period, mostly at grain fill stages (Ortiz-Bobea and Just 2013). Some other research also reported that crop yields reduce as temperatures increase. So, a warming climatic weather could damage crop productions and world food security (Schlenker and Roberts 2009).

Rice (*Oryza sativa* L.) is the primary staple crop after wheat and is the source of 50% calories for the almost 50% population of the world, and its demand will increase by 28% in 2050 (Zhu et al. 2018). However, rice production has stagnated in 35% of all rice-growing regions (Khoury et al. 2014; Zhu et al. 2018). Rice cultivation is very important because rice consumption is more as compare to other staple food. Rice cultivation is the source of earning for approximately 145 million people of the world and covering 165 mha which is about 11% of agriculture land. In current agriculture system, rice cultivation and farming system are coping with two tasks, one is providing adequate and nutritious food to meet the increased requirement of population and market, and second is to overcome climate change issue through sustainable agriculture escalation. So, rice cultivation deserves special attention concerning an interaction with climate change considering the increasing population pressure in future (Global Rice Science Partnership 2013). It also affects arable land and productivity of crops (Matthews and Wassmann 2003; Vaghefi et al. 2013). Therefore, it is essential to understand the factors responsible for low rice growth and production caused by climate change. Khanal et al. (2018) reported that increasing night temperature has been significantly reducing the rice yield. Normally, high concentration of atmospheric CO_2 increases global temperature but in very rare cases higher level of CO_2 in the atmospheric environment can enhance the plant growth and productivity (Kimball 1983). Previous different studies also showed that rice yield and production directly affected by increasing the global temperature (Subash and Ram Mohan 2012). It's very important to understand the present scenario of global climate change because it is directly linked to crop production and yield.

26.2 Current Status of Cultivation and Production of Rice

Rice is grown in almost all continents except Antarctica where plant growth is impossible due to low temperature (Lou et al. 2012). Among these continents, only Asia is cultivating 90% of rice and China (30%) is the largest producer followed by India (21%) and Pakistan (18%), whereas the rest 30% is contributed by Thailand, Indonesia, Japan and Burma (Calpe 2006). Further, rice becomes a major crop for many countries such as China, India, Indonesia, and Thailand (Nene 2012; Prasad et al. 2016). Rice is playing as game changer role in the economy of many countries including India (32.1%), Thailand (22.1%), Pakistan (8.9%), USA (8.3%), SR Vietnam (6.9%), Italy (2.8%), China (1.5%), Uruguay (2.1%), Australia (1.4%), and Brazil (1.6%) earning a foreign exchange by export (Workman 2015) (Fig. 26.1).

After the success of Green Revolution in 1960, the rice consumption per capita in Asia was increased from 85 kg to 103 kg during 1960–1990, whereas the global rice consumption was increased from 50 kg to 65 kg per annum. The increased use (150–350 MMT) of rice in the world was due to per capita consumption of rice by increased population of Asia (Wailes and Chavez 2012). The recent data showed that about 482 MMT of husked rice was produced in 2018 globally. Among the world countries, only China produced the 210 MMT rice which is the highest rice

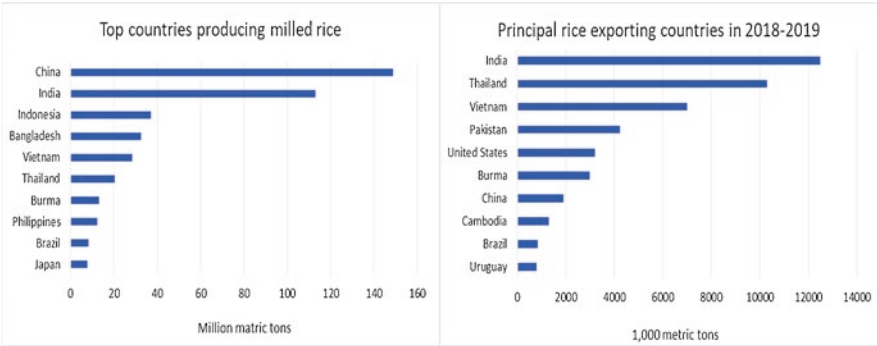

Fig. 26.1 Major Rice producing countries and exporting counties worldwide in 2018–2019. (Source: www.statista.com)

production after India. Total global consumption of milled rice was almost 477.77 MMT in 2016/2017. China being the largest rice consumer used 146 MMT rice to fulfill the demand of 65% rice using population. According to the FAOSTAT, (2015) the milled rice has a share of 500.5 MMT from 2524.3 MMT of total cereal production which increased from 24.6% to 28.1% from 1961 to 2007. It showed that globally rice production is only 20% of the total cereal production (Timmer 2010).

However, it is predicted from the market trend that the rice consumption in Asia will be increased at 1% per annum (pa) by 2020 and increase in rate of rice consumption in Asia would be higher than sub-Saharan Africa and Middle East (USDA 2013; OECD/FAO 2013; Wailes and Chavez 2012). It is also predicted that the area of rice cultivation will be increased to 160.5 M h with rice production of 502.7 MMT, and consumption of 501 MMT and average rice grain yield will be increase to 3.13 MT per h in 2021/2022 (Wailes and Chavez 2012). It is also predicted that the largest share of 30.1% of rice production in China in 2010 will be decreased to 27.3% in 2021–2022, while India's share of rice production might be increased from 21.5% to 22.4% from 2010 to 2021–2022. The rice production in Asia will be slightly decreased from 89.9% to 89.3%, while rice production in Africa will be increased from 3.4% to 4.2% from 2010 to 2021 (Wailes and Chavez 2012). Climate change about to rice production has to be considered from two aspects: one is to understand the climate change impact on future of rice production, and the second is to analyze the contribution of rice cultivation to climate change.

26.3 Climate Change: Is It Alarming for Agriculture?

Climate change is adversely influencing the global community and ecosystem by affecting the temperature of the earth, frequency of precipitation, solar radiation, winds, relative humidity and hydrological cycles. Due to the anthropogenic activities, fossil fuels burning and solar irradiance, earth is becoming hotter causing global warming. These combined effects of climatic factors decrease the agricultural production of many important crops. Global warming is also linked with the increased levels of greenhouse gases (GHGs), such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The impact of climate change is on agriculture, forestry, water resources, desertification, human health and ecosystem throughout the world. The burning of fossil fuels, manufacturing of cement, livestock and other agricultural practices, landfills, and other industrial activities are considered as the primary sources of the production of greenhouse gases and global warming. CO_2 is the most prevalent greenhouse gas responsible for 64% of global warming by anthropogenic activities. The emission of other gases is relatively in smaller quantity, but their heat-trapping ability is more than CO_2. CH_4 and N_2O are responsible for 17% and 6% human-made global warming respectively. Due to the high concentration of greenhouse gases in the atmosphere; the global temperature has been increased up to 0.85 °C in the late nineteenth century. The temperature increase of 2 °C is considered as a threshold level (IPCC 2013; NRC 2010; USGCRP 2014).

Among the human-made activities, agriculture is one of the leading causes of climate change as well as climate change affecting agriculture production. As concern with agriculture, the climate change has positive and negative impacts on agriculture by having noticeable effects on plant production, disease infestation, weed dynamics, soil properties, and microbial composition of the farming system. Temperature change could severely effect food production in tropical areas (IPCC 2007) with a predicted 30% loss of food production in South Asia in 2050 (Khanal 2009).

26.3.1 Agriculture Share Towards Climate Change

Agriculture sector is playing a vital role in food safety and sustainable development. Plants take up CO_2 and N from the atmosphere and soil for growth respectively. Many countries are emitting agricultural GHGs emissions, with highest emissions in 2011 were by China, United States, Brazil, Russia, Indonesia, India, Argentina, Pakistan and Myanmar, emitting 51% of agricultural emissions. The plant converts these gases into different pools, such as total biomass, plant residues, and soil organic matter (SOM). As a results of plant respiration, decomposition of plant residues, SOM and combustion of plant residues, the CO_2 and other GHGs, mainly CH_4 and N_2O are again released to the atmosphere. Similarly, anthropogenic activities, afforestation, crop land management, and changes in land cover (wetlands, forests, and grasslands) cause changes in natural fluxes. Human-made activities effect both CO_2 sources (deforestation and peatland drainage) and CO_2 sinks (management for soil carbon sequestration and afforestation), and other GHG emissions from agriculture such as CH_4 from rice cultivation and livestock, N_2O from biomass burning, fertilizers and agricultural soils (IPCC 2014).

Agriculture is one of the principal reasons for GHG emissions, contributing 10–20% of the total GHG emissions (IPCC 2013; FAO 2009). Agriculture has dual roles; both a source and a sink for GHGs. These GHGs emission come mostly from agriculture sector such as the crops cultivation, deforestation, and livestock, which is approximately 20% of emissions from agriculture sector (IPCC 2014; FAO 2014). With increased usage of chemical fertilizers, N_2O (65–80%) emissions is contributing the depletion stratospheric ozone along with greenhouse effect. About 90% of N_2O is formed from the microbial transformation of NO_2^- and NH_4^+ in water and soil. The agriculture-related activities are the source of different greenhouse gases. For example, contribution of agricultural activities to greenhouse gas emissions by rice cultivation (CH_4, 11%), enteric fermentation (CH_4, 32%), manure (CH_4, N_2O, 7%), biomass burning (CH_4, N_2O, 12%), and soil emissions (CH_4, N_2O, 38%), afforestation and forestation (CO_2), and drained peat and peat fire (N_2O, CH_4 and CO_2) (Khanal 2009).

26.3.2 Effects of Climate Change on Agriculture

FAO (2015) reported that world's agriculture, aquaculture, and forestry are ensuring food security for 3 billion people by 2050 to meet the 60% more food production in the world. In the current alarming climate changes, attaining food security is most crucial especially in the developing world. Climate change is influencing agriculture by biophysical and socioeconomic ways. Physiological impact affects plant growth by disease, weed, soil water resources, increasing temperature and sea levels. Whereas, socioeconomics impact the crop yield and ultimate GDP from agriculture, effect geographical trade regimes, enhance people hunger, food security and social unrest (FAO 2009; Khanal 2009). The critical analysis revealed that climate change has both negative as well as positive effects on plant production. The high temperature in high altitude areas and towards the poles, decrease the growth period of crops and increase the possibility of completion of two cycles in the same season. Moreover, higher temperature helps the decomposition of OM, enhance the nutrient uptake, nitrogen fixation, and root development mechanisms. However, the high temperature could be harmful to lower altitude areas of the world, where already warmer conditions. When the temperature is higher than the optimal level in the region due to climate change, CO_2 releasing rate is increased while the photosynthesis activities reduced which finally affect the plant physiology and yield. Similarly, high temperature or warmer condition than optimal range, insect pest growth increase and increase the chance of reduction of plant production. Climate change also affects the extent and pattern of rainfall, and evapotranspiration rate which disturb the soil water contents, drainage, runoff, and water uptake by plants. Both flooding and drought affects the growth stages of plants such as flowering, pollination and grain filling stages (Khanal 2009).

Agriculture is one of the principal sources of GHG emission contributing 10–12% of the total GHG emissions (IPCC 2013). Agriculture has dual roles, both a source and a sink for GHGs. As far as the rice production is concerned, cultivation of rice, excessive use of fertilizers and soil amendments, and burning of rice residues give rise to the tremendous amount of GHG emissions (Vibol and Towprayoon 2009; Zheng et al. 2010; Tivet and Boulakia 2017). From these emitted GHGs in the rice ecosystem, CO_2, CH_4, and N_2O are the major contributors. By 2011, it was discovered that the contribution of CH_4 and N_2O emissions from the agricultural system was up to 32% and 69%, respectively, of all GHGs (IPCC 2013).

26.4 Impacts of Climate Change on Rice Agriculture

Rice is a key staple food crop; however, its growth and productivity are affecting by climate change. The low production along with high demand is due to climate change which affecting food security and economy of the world. Amongst the impacts of climate change, the high duration and intensity of high temperature results in drought, floods, and tropical storms and effects the distribution of rainfall, cause soil degradation, and intrusion of agricultural land by saltwater due to rise of sea level (Fig. 26.2).

26.4.1 Climatic Factors Affecting Rice Cultivation

There are many climate factors affecting the rice cultivation such as: rainfall, temperature, day length and sunshine. Rainfall is the most important element among the climate factors for rice cultivation. The rainfall distribution in different areas is influenced by the topographic factors such as mountains and plateau.

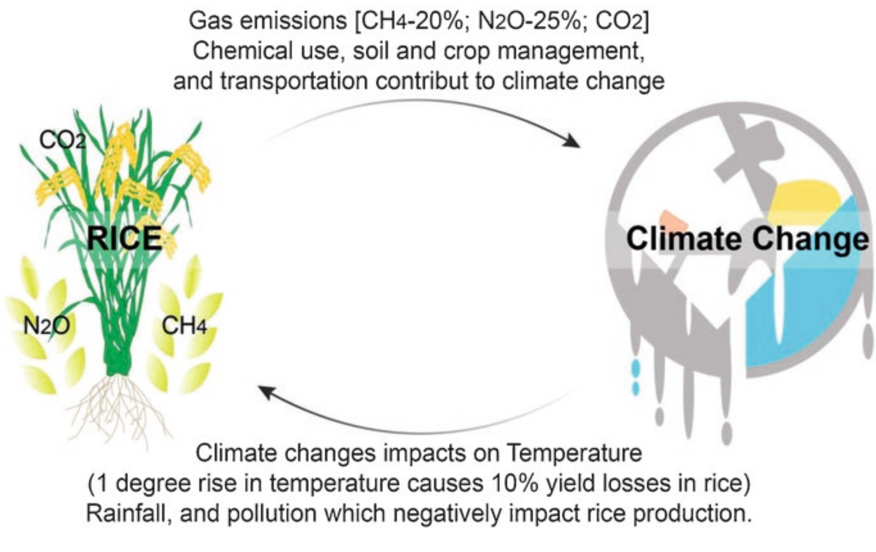

Fig. 26.2 Role of rice cultivation on climate change and counter effects of climate change on rice production

Temperature is an important climatic factor having some positive and negative impacts on the growth, development and yield of rice. Rice is grown in tropical and sub-tropical climate and requires relatively higher temperature, optimally from 20 °C to 40 °C, with 30 °C and 20 °C day and night temperature. Rice requires different critical temperature at different growth stages such as ranging from 16 °C to 20 °C at flowering and fertilization, and 18 °C to 32 °C at ripening. Whereas, temperature higher than 35 °C affects grain filling. Previous research also indicated that the rice yield declined 10% by every 1 °C increase in minimum night temperature (Khanal et al. 2018).

Solar radiation is essential source of energy for crop growth. The rice yield is significantly affected by the solar radiation predominantly the last 35–45 days of ripening period. The effect of solar radiation is more prominent when other factors such as water, temperature and nutrients are not limiting. Ripening stage required abundant radiations and low temperature for accumulation and translocation of carbohydrates to grains. Thus, the rice growing seasons differs in different parts of the world, depending on the climatic conditions at specific growth stage. If temperature is favorable for rice cultivation throughout the year then, two or three crops of rice could be grown in a year. Where rainfall is high and winter temperature is fairly low, only one crop of rice is grown (Porter et al. 2014).

26.4.1.1 Climate Change and Rice Cultivation

Cultivation of crops is defined as the process of a crop's natural growth. This biological growth or crop cultivation consists of distinctive, chronologically progressive stages in plants. The progress of crop growth depends on the need for growth and development to a given physical input varies across different growth phases (Felkner et al. 2009). After wheat and maize, rice is also a significant cereal crop and over three billion people are consuming as a staple food. Moreover, rice cultivation and production is an important source of income for over 100 million families in the world especially in Africa, Asia, and America (Nguyen 2006). Climate changes refer to any variation in a climate with time due to anthropogenic and natural activities (IPCC 2001). Climate changes in the form of reduced rainfall, higher temperatures and high variability in rainfall directly affect the crop yield as well as net agricultural revenues (FAO 2009). The negative effects of climate changes would take a unique toll on food security and crop production particularly in developing countries where they have very low ability to adapt and manage these challenges. Now as days, the fast-growing consensus is that global impact of climate changes has a directly negative effect on crops as well as farmers income (Khanal et al. 2018). Different agronomic research indicates that increased rainfall can have positive outcomes on crop growth and yield, but the impact of rising temperature depends on crop type and agro-ecological zone.

Recent studies show that a slight variation in temperature will hurt main crops such as wheat, maize, and rice (Khanal et al. 2018; Sarkar et al. 2009) also showed that increasing the mean global temperature would responsible for a significant reduction in rice production in the world. Additionally, different research studies have confirmed that the cultivation and production of rice crop might be greatly affected by climate change. Another study showed that climate change has the main factor to affect the rice cultivation and production directly by water stresses and heat (Porter et al. 2014). When temperature increases, the rice crop maturity, and yield reduce up to 8% and 12%, respectively (Saseendran et al. 2000). Similarly, Darwin et al. (2005) estimated that about half of the rice cultivation and production would be reduced during the next century due to global climate change (Fig. 26.2).

Globally, the speed of climate change is high. It is estimated that, in India, the rice production would be reduced by 4.5% to 9% because of climate change by 2039 (Guiteras 2009). In Nepal, the reduction will be estimated up to 10% due to soil moisture content changes (Stuecker et al. 2018), while, changing in the rainfall patterns will be a great threat for Indonesia because their agricultural activates directly linked by rain (Ruminta et al. 2018). In Zimbabwe, it was estimated that rice production would be decreased up to 65% with a 2 °C temperature rise (Downing 1992). In Philippine, every year rice yield reduced by 15% per 1 °C increase in global temperature (Peng et al. 2004). Similarly, the temperature and rainfall are the key factors that affect the rice cultivation and production like 1% rise in rainfall leads to 22% increase in rice yield while 1% increase in temperature reduced 4% rice production in Nigeria (Nwalieji and Uzuegbunam 2012).

26.4.2 Effects of Climate Change on Rice Production

Climate change causing severe damages to rice spectra throughout the globe. The less supply of rice besides high demand is affecting food safety as well as the country's economy. Further, the increasing temperature, and length of extreme climate occasions i.e. soil degradation, drought, floods, and tropical storms, unequal and unpredictable of rainfall and high sea level, and loss of agricultural land are due to climate change (Fischer et al. 2002). High sea level and temperature are the main causes of salt affected soils, makes the soil non-productive and reduces rice productivity at a remarkable rate from the highly productive rice land. Similarly, drought has negative effects rice growth stages and development such as reduction of spikelet fertility and panicle exertion ultimately yield loss. Moreover, frequent drought reduces water supply as well as increase the demand for plant transpiration water (Felkner et al. 2009; Richardson 1981). Climate change also causes rice diseases such as sheath blight, rice blast, and culm blight could become more widespread by changing the patterns of winds, and produce the agents of crop disease which spread the wind-borne bacteria, pests, and fungi. The crop-pest interactions may alter the timing of development stages in both hosts and pests. To handle this pest infestation, cause high use of chemical pesticides to control them ultimately cause environmental pollution or climate change (Khanal et al. 2018). Climate change might also affect the evolution species of weeds, ecology of weeds, and weed specie's competitiveness of C3 vs. C4.

26.4.2.1 Increase of Carbon Dioxide (CO_2) on Rice Production

The Increasing atmospheric CO_2 concentration has an encouraging effect on plant life cycle, which provides protection against increasing temperature for microsporogenesis, flowering process, and grain-filling mechanism. For example, every increase of 75 ppm atmospheric CO_2 concentration, the increase of 0.5 t h^{-1} rice yields occurs.

26.4.2.2 The Effects of Increasing Temperature on Rice Production

The temperature has antagonistic effects on grain yield of major crops including rice. Every increase in 1 °C temperature reduced during dry season 5–7% or about 10% grain yield. Heat stress, high respiration rate, decreased sink formation, and short growth periods are the main causes of grain yield reduction. According to the Asian Development Bank's report, a 4 °C increase in temperature could decrease 75% rice yield in the Philippines. However, the temperature sensitivity depends on the nature of rice cultivars and growth stages. Through the early or vegetative rice growth stage, an extreme temperature decreases numbers of tiller per plant, plant height, affects panicle and spikelets development. Additionally, the exposure of more than 35 °C for a short time (few hours) decrease pollen viability and increased spikelet sterility in rice plant. Flowering is the highly sensitive to high temperature in which heat stress might lead to inactivity of panicle dry weight during the reproductive stage.

Similarly high temperature affects cellular and developmental processes leading to reduced spikelets fertility and grain weight, grain quality (high % chalkiness and low grain amylose content) during the grain filling and ripening phase of rice. The shortening of the plant growth cycle due to steady increased temperature harms rice yield. An increase in temperature is likely to cause high evaporation from the soil and accelerated plant transpiration rate which might cause osmotic stress. High evaporation from the soil also increases the soil salinity. Similarly, high air temperature is expected to boost up the decomposition of soil organic matter (SOM) naturally and upturns the physical and chemical soil properties that disturb the soil fertility. Along with this, high temperature accelerates many microbial processes in the flooded soil water which results in reduction of the rice productivity.

26.4.2.3 The Effects of Greenhouse Gases on Rice Production

The emission of GHGs from terrestrial to atmospheric environment is also responsible for increasing the global mean temperature. Several years ago, agricultural was the first evidence point of human-caused enhances GHGs emissions in the atmospheric environment (Paustian et al. 2006). Agriculture contributes approximately 10–14% of total global GHG emissions. Methane (CH_4) emitted from paddy fields accounts for 17.9% of the total CH_4 emissions which is responsible for climate change in the world (Yan et al. 2009). Another study also showed that CH_4 emission from rice fields had been recognized as a great contributor to global warming (Nguyen 2006). It is also observed that CH_4 emission at its peak in tillering and heading stage of the rice crop and that is a major factor in increasing the global temperature (Sriphirom et al. 2019). The increasing global mean temperature may reduce the rice spikelet and increase the spikelet's sterility, which affects the crop production while on the other hand; increasing the concentration of atmospheric CO_2 could improve the rice production and yield (Dabi and Khanna 2018). A similar study also showed that the higher concentration of CO_2 due to global warming could be increased the rice production (Nguyen 2006). Overall, climate changes due to natural and anthropogenic sources may directly or indirectly effect the rice cultivation and production. Thus, the GHG emissions from paddy lands during the whole agriculture process have alarming global warming potential, and steps should be taken to reduce or curb the same (Fig. 26.2).

26.4.3 Influence of Rice Cultivation to Climate Change

Rice is grown under the flooded condition in most parts of the world. Flooded rice fields or paddy fields release handsome amounts of methane (CH_4), and burning of rice straw and direct rice straw incorporation to the soil also emit GHGs to the atmosphere. Rice cultivation causes the emission of GHGs mainly by two approaches, one by burning paddy straw (emission of CO_2, CH_4, and N_2O), and second by anaerobic flood-irrigations (causing CH_4 productions). The annual CH_4 emission from rice soils have been assessed up to 36 Tg annually, which contribute about 18% of the total anthropogenic based CH_4 emission to the atmosphere (IPCC 2013; Tivet and Boulakia 2017). Further, the production of rice straws in Southern Asia and South-Eastern Asia is about 215,600 and 210,600 Kilo Tons, respectively. Thus, the burning of a high amount of rice straws or the stubble can cause huge GHG emissions. For instance, stubble burnings in the paddy fields of Cambodia caused about 75.8 K Tons of GHG emissions (Vibol and Towprayoon 2009). In the regions, where mechanization is common for rice harvesting such as China, Thailand, and northern India etc., the straws remain in the paddy fields and mostly burned in situ. This multi-country practice has raised critical concerns for environment safety and global warming, as an increase of this practice has been anticipated from 600 million tons in 2000 to 930 million tons by 2030 (Kubo and Purevdorj 2004; Singh and Strong 2015).

The phenomenon of methane emission to the atmosphere is that the CH_4capture significant amount of heat from the atmosphere and 21 times more heat absorption capacity than carbon monoxide (CO) with sustainability about 9 to a 15-year lifetime in the atmosphere over 100 years. Therefore, CH_4 is considered as the main contributor to the climate change and global warming due to its greenhouse (GH) effects. Similarly, excessive use of inorganic fertilizers and pesticides also releases nitrous oxides (N_2O). Increase of rice cultivation areas also altering the land cover and eventually changes its potential of heat and light to absorb or reflect (Fig. 26.2).

26.4.3.1 Methane (CH_4) Emission from Rice or Paddy Soil

In flooding conditions of the rice field, the anaerobic condition occur due to unavailability of oxygen supply from the atmosphere to soil and results in anaerobic fermentation of soil organic matter. Under this anaerobic condition, the methanogen microbes in rice fields are responsible for the production of CH_4, which contributes about 14% GHG emissions in the environment (EPA 2006). The CH_4 emit from submerged or flooded soil to the atmosphere by diffusion and release of gas bubbles via rice roots and stem. The potential of CH_4 emanates more when the rice fields with standing water (2–5 cm) throughout the rice crop growth cycle than the dry areas during the offseason. Therefore, CH_4 emissions are insignificant in upland rice growing systems due to non-flooded rice cultivation for an extended time span. Whereas, in rain-fed areas, the CH_4 emission is much lower due to no standing water during the rice growing season.

26.4.3.2 Factors Affecting the CH_4 Emission from Paddy Soil

26.4.3.2.1 High Use of Inorganic Fertilizer

After the green revolution in Agriculture, the excessive usage of chemical fertilizers and organic nutrients resources such as urea, green manure, poultry and animal manure, and rice straw increase CH_4 releases. This CH_4 emission is based on the fertilizer's quality, the timing of application, and quantity. Furthermore, temperature and water management might be able to reduce or increase these fertilizer impacts on CH_4 emission.

26.4.3.2.2 Water Management

Standing irrigation water or flooded soil is a precondition to the persistent release of CH_4. The fluctuation in CH_4 emission depends on water management. This fluctuation varies in water level amongst the submerged field (reductive condition) and drained field (oxidative condition), depending on water management. Therefore, rice/paddy environments with a steady supply of water (irrigated rice) have high CH_4 emission potential than the unsteady supply of water (rain-fed rice growing areas).

26.4.3.2.3 Soil Types

The emission of $CH_4$is lower in permeable soils (sandy and sandy-textured loamy soils) due to high filtration rates than in heavy clay soils. The mechanism in which the water enters into the soil from the surface is called infiltration. Light-textured soils have high porosity, so flooded water cannot be retained longer compared to heavy clay soils. During this phenomenon, high clay textured soils need a high-oxygen supply, which hampers CH_4 emission even with high organic inputs availability.

26.4.3.2.4 CH_4 Emission and Rice Cultivars

The emission of CH_4 from flooded paddy fields depends on rice cultivars. This variation depends on morphological traits of rice cultivars such as root growth and root exudates, biomass, and several tillers, above-ground biomass production, and duration of rice growth play an essential role in the alteration of CH_4 emissions.

26.4.3.2.5 CH_4 Emission and Temperature

The emission of CH_4 will be on the peak after the exposure of high temperature during the weeks along with the fertilizer and organic inputs application. The daily emission of CH_4 correlated with temperature, as temperature increased, higher the organic matter decomposition rate. The CH_4 and temperature fluctuations are also depended on rice growth stages. This fluctuation is more in early rice seedling stage and lowers at the time of the lateral growth stages when the rice plant canopy shaded the soil.

26.4.3.2.6 Soil Tillage and CH_4 Emission

Tillage disturbs the soil texture and exposes the stored CH_4 from the soil. The speed of CH_4 emission varies according to the climate type after tillage action.

26.5 Strategies to Handle the Effects of Climate Change on Rice Production

The mitigating and adaptation approaches are need of the hour to cope with the global warming caused by the climate change. The fine-tuning in eco-system and socio-economic system in response to climate inducements and their special effects is called adaptation. Whereas adaptation states to immediate actions, mechanisms, in a system at social strata to country level to handle with, managing or adjusting the changing conditions, hazards, opportunities (Smit and Wandel 2006; McCarthy et al. 2001), such as adaptation subjected to climate change is the managing of natural diversity, and mitigation is a human interference aimed to overcome the GHGs levels in the ecosystem or increase GHGs sinks for carbon storage. Similarly, extensive plantation is the main source as a mitigation strategy against climate change, and to avoid GHGs emissions through high storage of carbon.

These adapted measures mean that asses the worse impacts of climate change and taking appropriate steps to stop or minimize the damages. There are many environmental factors (temperature, drought, greenhouse gases, etc.) having negative impacts on rice production which need to address. Poor farmers belong to developing countries, especially South Asian countries are most affected by the climate change. Although, many efforts have been made to adopt some measures to climate change by many countries global warming continues to increase in various parts across the globe.

26.5.1 Mitigating Techniques or Practices to Hinder GHGs Emissions from Paddy Fields

26.5.1.1 Mid-Season Drainage or Alternate Wetting and Drying

During rice growth cycle, the draining of paddy fields at the middle of the rice-growing season or wetting and drying is a better water management exercise than constant flooding irrigation. This mid-term drainage practicing has been proved to decrease CH_4 release up to 80% without rice grain yield. However, this option is not suitable for lowland rice fields with consistent water supply and availability. This technique needs good care and proper management. Because, it has disadvantages to increasing weeds during the non-flooded period, and results in increased emissions of nitrous and ultimately loss in rice yield potential. Many countries such as Philippines, Japan, India, Indonesia, and other countries have studied that these water management practices effectively reduced CH_4 without affecting rice yield. The farmer can also try to avoid water logging in the offseason.

26.5.1.2 Adaptation of Direct Rice Seeding

Direct rice seeding method has been shown to reduce CH_4 emission by shorter flooding period and decreased soil disturbance. About 16–54% CH_4 emission reduces by following the direct rice seeding methods compared to transplanting rice seedlings (Corton et al. 2000).

26.5.1.3 Short Term Vegetation

Short term vegetation could be done between successive agricultural crops, because it helps to lessen carbon losses through soil erosion and N_2O emission, and increase the storage of soil carbon. The short-term vegetative cover has many useful effects such as enhancement the quality of soil and water holding capacity (WHC), soil erosion prevention, and improves the microbial communities to conservation the biodiversity.

26.5.1.4 Focus on Nitrogen Use Efficiency (NUE) for Precision Farming

The wise use of nitrogen for the soil quality and to make it more available to plant roots or efficiently release of N_2 fertilizer. For better NUE, it is suggested that apply the rule of the right time, the right requirement of nitrogen, and the right amount of nitrogen fertilizers when least susceptible to losses. For this purpose, the Minus-One Element Technique (MOET) and Leaf Color Chart (LCC) are two famous techniques are available to assess and monitor the N_2 requirement as well as nutrient deficiency of the crop. These techniques are easy to use and economical analytical tools for checking NUE.

26.5.1.5 The Wise Use of Inorganic and Organic Fertilizers

The nitrogen fertilizer containing sulfate i.e., ammonium sulfate $(NH_4)_2SO_4$ reduce about 25–36% CH_4 emission. Similarly applications of urea with phosphor-gypsum reduce the CH_4 emission up to 70%.

26.5.1.6 Use of Rice Cultivars with Low Methane Emission Potential

Rice cultivars having small root systems, high root oxidative activity, and harvest indices, and more productive tillers emit less CH_4 than other rice cultivars. This is the most easily adaptable option with existing varieties, but CH_4emission reductions are significantly less than other climate change mitigating strategies.

26.5.1.7 Improve Tillage Practices

CH_4 emission is very extreme during the tillage practices for the preparation of rice field. After the harvesting of previous agricultural crops, the stored CH_4 in soil release at the time of tillage practices during preparation rice field. The high soil carbon losses occur due to soil erosion and decomposition during the conventional tillage practices. However, carbon level could be sustained in the soil by cultivating agricultural crops using minimal or zero tillage, because no-tillage or zero tillage results in the lowest CH_4 emission than conventional tillage system in irrigated areas.

26.5.1.8 Management of Crop Residues

A wise use of compost than fresh rice straw flood irrigation system reduces CH_4 emission up to 63%. Similarly, proper use of by-products of farm i.e., rice hull, coffee hull, and corn cobs, could be the wise option as fuel for purpose of drying and heating. Along with this, the farm waste can be used as organic fertilizer after recycling. There are many technologies for utilizing rice hull biomass including the Rice Husk Gasifier Engine System, Maligaya Rice Hull Stove, and Maligaya Flatbed Dryer, are inexpensive and environment-friendly. These techniques increase vegetation and stocks of biomass, which result to increase in storage of soil carbon and decrease N_2O emission.

26.5.1.9 Application of Methanotrophs

The methanogen microbes in rice fields are responsible for the production of CH_4, which contributes about 14% GHG emissions in the environment (EPA 2006). In the past, several efforts, including the organic and inorganic nutrients management have been made to control the CH_4 emissions from paddy fields. However, no long lasting and promising solution to this problem has yet been established. In this regard, the efforts to inoculate the CH_4-oxidizing microbes, such as methanotrophs belonging to Proteobacteria, NC10 phylum, and the Verrucomicrobia, which are capable of using CH_4 as a carbon source and lowering the atmospheric CH_4 emissions in the soils (Ettwig et al. 2010; Conrad 2009; Cui et al. 2015) haven't been used to mitigate the CH_4 in paddy crops. These methanotrophs are particularly appealing as bioremediation agents in CH_4-containing environments (paddy fields) and ranked as an essential global CH_4 sink.

The methanotrophic endophytes have been reported to work as natural CH_4 and have a range of 50–77% ability to reduce CH_4 and CO_2 emission from peatlands, and other plants depend on season and host plant (Kip et al. 2012; Goraj et al. 2013). Methanotrophs have two types, the aerobic CH_4-oxidizing bacteria (MOB) and anaerobic oxidization of CH_4 (AOM) is reported in many plants such as peat mosses and mosses (Sphagnum sp.) (Kip et al. 2012; Dedysh 2009). The anaerobic oxidation of CH_4 (AOM) containing anaerobic methanotrophic (ANME) archaea which are big CH_4 sink to play a significant role in global warming. As concern with ANME, the ANME-2d reported in wetland and represented within the euryarchaeota and gain energy from the AOM, with sulfate as the final electron acceptor and removes the greenhouse gas CH_4 from anoxic environments and reduces its flux to the atmosphere.

$$CH_4 + SO_4^{2-} \rightarrow HCO^{3-} + HS^{-} + H_2O \tag{26.1}$$

However, to remove the long-lasting effect of GHGs from the paddy field is essential. The CH_4 removal efficiencies by the aerobic and anaerobic MOB are reported in marine environments, while AOM was observed as CH_4 sink in freshwater bodies, and role of inoculation of aerobic and anaerobic methane-oxidizing bacteria in paddy crop could be better option to reduce the CH_4 and other GHGs emissions from paddy fields.

26.5.2 Integrated Rice-Based Farming and Cultivation System

Rice production, for the better climate change conservation, need to adopt a rice-based diversified, integrated farming system. For example, the Palayamanan System model for PhilRice has been developed to help farmers of rain-fed and upland areas to sustain better cope with adverse impacts of climate change and their livelihoods. Palayamanan System model highlights the purposeful integration of many farming mechanisms such as rice and other crops, livestock, and aquaculture. Through this system, farmers can get many benefits to include nonstop food supply, improved crop productivity, and sustainability, fewer productivity hazards, higher income, better resource allocation, and improve diversity and ecological balance.

26.5.3 Integrated Rice Crop Management System

The many impacts of climate change can be offsets by rice production and increasing rice productivity and profitability for the farmers. For example, by adopting the Palay Check System, farmers can produce more rice for their family and ultimately less hunger and increased income for farmers. Palay Check is a dynamic crop management system for rice is helps the farmers to follow easy farming practices and to improve crop yield and input use efficiency (IUE). The Integrated Rice Crop Management System also has a high potential for climate change mitigation in irrigated lowland rice farming systems.

26.5.4 Genetic Engineering in Rice Cultivars with Better Tolerance to Adverse Climate and Higher Yield Potential

The best option to cope with the climate is the development of high-yielding and stress-tolerant varieties such as temperature, salinity, drought resistant rice cultivars. Rice genetics and breeding scientists have successfully developed promising rice varieties resistance to extreme climate conditions such as drought (NSIC Rc192 (Sahod Ulan 1) for rainfed-lowlands and NSIC Rc9 for upland areas), salinity (NSIC Rc182 (Salinas 1), Rc184 (Salinas 2), Rc186 (Salinas 3), Rc 188 (Salinas 4), and Rc190 (Salinas 5). varieties (NSIC Rc192, NSIC Rc9, NSIC Rc182, Rc184, Rc186, Rc 188, and Rc190) also have good milling recovery and good eating quality, and submergence stress. Submarino1 could survive, grow and develop even after 10 days of complete submergence at vegetative stage.

26.5.5 Adoption of Water-Saving Technologies

Another option to handle climate change effects is needed to adopt water-saving techniques such as controlled irrigation, aerobic rice, hydroponic seed culture, and harvesting of rainwater. Furthermore, controlled irrigation helps to reduce irrigation water (16–35%) demand in rice growth cycle without decreasing production. Consequently, number of farmers having the farms near the tail-end of the irrigation system can get the benefit, and reduce the farm inputs, results in increase farmer's income. It also decreases the CH_4 emission, which is higher in constant flooding irrigation method during rice cultivation. It is also a good option to improve the irrigation infrastructure's design, construction, and maintenance of irrigation water.

26.5.6 Agronomic and Farm Level Management Strategies

Framers could avoid the effects of climate change by the development of techniques such as weather proof farming equipment and using post-harvest facilities. Adopting climate smart cropping pattern by shifting the planting date and adjusting cropping season to avoid certain harsh weather such as to avoid heat stress at reproductive stage could reduce the risk of heat induced losses. Furthermore, using resistant genotypes could reduce the effect of abiotic stress.

26.5.7 Financial and Technical Assistance to Farmers

Support to farmers and small-scale financial aids could be granted to invest in rice farming by the foundation or government to adopt modern technology. Financial losses could be handled by adopting the risk sharing and transfer schemes for farmers such like compensation, crop insurance, and calamity funding will reduce the financial losses. Raising awareness for new technologies and building capacity by public service announcements, farmer engagement and better extension services by using communication techniques like SMS alerts and internet and modern information.

26.5.8 Monitoring and Forecasting System

Climate forecasting and monitoring system could be developed for rice farming by using remote sensing. As well as modeling, simulation and mapping for the areas which are most affected by drought, flooding, high or low temperature or other stress by climate change would be helpful.

26.5.9 Breeding Strategies to Cope the Effect of Climate Change on Rice Production

Improvement of tolerance of rice crop is necessary in order to reduce the negative effects of changing climate. In spite of different agronomic and management approaches, wide research is going on to develop better breeding techniques to enhance abiotic resistance (Fig. 26.3). In past, plant breeders were more focusing on

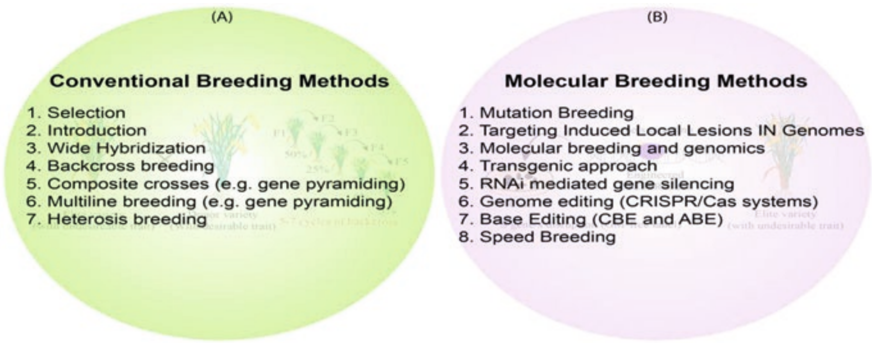

Fig. 26.3 Breeding strategy for climate change management. (**a**) Conventional plant breeding methods; (**b**) New plant molecular breeding methods

breeding for biotic stress and most importantly disease resistance but with sudden changes in climate and prevalence of abiotic stresses like cold, heat, salinity and water stress has shifted the priority of plant breeders to abiotic tolerance. Since long time, many rice cultivars have been developed using different classical and conventional techniques like selection, composite crossing, hybridization and backcross breeding. But these methods were proved as less efficient, expensive, labor intensive and slow to enhance crop resistance. Moreover, the slow time-consuming methods are less affordable to cope with the rapidly changing climate induction of biotic resistance. Hence, there is the need of time to utilize the modern and robust molecular genetics approaches like recombinant DNA technology, marker assisted selection (MAS), mutation breeding, virus induced gene silencing (VIGS), targeted induced local lesions in genome (TILLING), and recently genome editing through clustered regularly interspaced short palindromic repeat (CRISPR)/CRISPR-associated protein (CRISPR/Cas) systems to improve the resistance against stresses in crops specially in rice (Fig. 26.3).

Crop improvement through conventional and modern plant breeding helped the breeders in developing high-temperature (heat), chilling and drought tolerant rice cultivars. Overall, developing a variety tolerant to abiotic stress is very tedious, time consuming and complex work. The mechanism underlying abiotic stress tolerance in plants is not well understood. Different studies based on 'omics', which can unearth not only the highly informative expression patterns of genes/proteins but also show the variation of response among genotypes with different stress tolerance, have been performed to understand the mechanism behind abiotic stress in plants (Xu et al. 2015; Wang et al. 2016; Mu et al. 2017). The applications of new techniques are gaining fame among the plant biologists particularly a new approach known as top-down approach which involves metabolic network reconstructions using 'omics' data (e.g., metabolomics, transcriptomics, proteomics, genomics etc.) generated through DNA microarrays, RNA-Seq or other modern high-throughput genomic techniques using appropriate statistical and bioinformatics methodologies (Shahzad and Loor 2012).

The improvement of crops against different stresses aims to improve the yield to feed the ever-growing population of the world. Therefore, yield under drought can be evaluated to screen drought tolerance rice genotypes. Quantitative trait loci (QTLs) related to drought resistance is identified with the help of QTL mapping. The regions of chromosome responsible for drought tolerance are tagged with the help of molecular markers. Likewise, Sahbhagi Dhan, an Indian variety released and notified in 2010, showed a constantly good performance under rain-fed transplanted low land and directs seeded upland conditions (Dar et al. 2012). A variety named Vandana tolerant to drought has been developed by MAS (Bernier et al. 2009). New drought-resistant rice varieties such as RD12 for glutinous and RD33 for non-glutinous rice are also being produced with the application of DNA technology. Oryza glaberrima, being wild species, carries two awesome characteristics such as early-morning flowering habit and high transpiration rate with sufficient water which are convenient traits and help rice plant for avoiding heat stress. It has been a great genetic source for molecular plant breeders since its discovery (Markam

2013). The study of rice proteomics and the availability of different data bases are a good source to unravel the functions of proteins involved in different traits of agronomic importance, such as drought tolerance. A comparative study of root cytoplasmic proteome was done in PEG induced drought conditions for a drought tolerant rice cultivar and it were found that the largest percentage (29%) of identified proteins involved in bioenergy and metabolism. Moreover, mainly proteins were consisted of malate dehydrogenase, succinyl-CoA, putative acetyl-CoA synthetase and pyruvate dehydrogenase, etc. which showed a large contribution toward drought regulatory mechanism in rice (Agrawal et al. 2016).

Similarly, the application of molecular genetic tools has been instantly sought out the problem of chilling stress in rice plants. It is reported that the molecular techniques have been useful to improve rice chilling tolerance in order to maintain rice production. It was found that overexpression of COLD1jap significantly enhances chilling tolerance, whereas rice lines with deficiency or down regulation of COLD1jap are sensitive to cold (Ma et al. 2015). OsCTZFP8 is a C_2H_2 zinc finger transcription factor that plays an important role in cold tolerance in rice (Jin et al. 2018). Multi-locus probability tests and linkage disequilibrium (LD) analyses detected 46 functional genetic units (FGUs) (37 single loci and 9 association groups or AGs) distributed in 37 bins (~20%) across the rice genome for Cold Tolerance (Liang et al. 2018). Additionally, it is found that the improvement of cold tolerance via genome editing can significantly enhance rice productivity in short period of time. In this regard, CRISPR/Cas9 technology was employed to edit a transcription factor namely TIFY1b, one of the cold tolerant involving genes discovered in rice, and its homology gene TIFY1a (Huang et al. 2017). Site-specific mutations were observed in T0 rice plants and identified the suitability of adaption of rice to low temperature regions.

In conclusion, there are several options to counter the effect of climate change on rice production but the crop improvement approach is one of the best ways to mitigate the negative effects of changing climate such as heat, chilling, drought etc. Number of studies have been published and lots of work have been done to counter the impact of climate change in rice but there is still need to develop climate resilient rice. Climate robust rice system should be designed to cope with increased risk of changing climate. Nowadays, genome editing has revolutionized the agriculture, especially brought major improvements in rice, and we will certainly witness more applications in near future (Mishra et al. 2018; Zaidi et al. 2019). It may be one of the robust, efficient and user-friendly approaches to improve the crops against different a/biotic stresses. Besides that, another technique, speed breeding, is also in and will be utilizing soon in near future for crop improvement. Its successful applications in wheat have already been published (Watson et al. 2018). Altogether, the conventional and molecular breeding methods, along with genome editing and speed breeding tools can play a significant role in the development of climate resilient rice varieties.

26.6 Conclusion

Taken together, it improves our understanding that not only the rice is affecting climate through the emission of methane and different other greenhouse gases but also the adversely changing climatic conditions are threatening the rice production worldwide. Plant breeders are making their great contribution in the development such verities which can resist the harsh weather conditions and different environmental stresses. The utilization of different new plant breeding tools such as CRISPR/Cas systems have made it easy for plant breeders to develop resistant verities more rapidly and efficiently. However, in future, we certainly witness further strategies that would be used in the improvement of crops against changing climate.

Acknowledgment Sajid Hussain is thankful for the award of a Postdoctoral Fellowship from the Chinese Academy of Agricultural Sciences, China. SH increase thanks to Stat Key laboratory of Rice Biology, China National Rice Research Institute, Hangzhou, China for providing research facilities and friendly working environment.

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