Mirza Hasanuzzaman *Editor*

Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives I

General Consequences and Plant Responses

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This book is dedicated to
Prof. Dr. Md. Fazlul Karim *(left)*
and
Prof. Dr. Md. Rafiquel Islam *(right)*
of Sher-e-Bangla Agricultural University,
Dhaka
who inspired me in the journey of teaching.

Preface

Impact of climate change is expected to be broadly negative, including reduced water availability, salinity, flood, and infestation of pests and diseases. Due to the significant climate change over the centuries, the incidence of various abiotic stresses such as salinity, drought, extreme temperature, atmospheric pollutions, and metal toxicities regularly affect plant life and productivity. Many crops perform only at 30% of their genetic potential under adverse environmental conditions. The predictable loss of crop production is as much as 70% in an average and might be 100% in extreme cases. The resulted economic loss caused by environmental stress is a great concern in agriculture.

To sustain productivity against the environmental stresses, the crucial importance is to know and understand the plants-specific responses to the different environmental factors. Plant ecophysiology is the science of interaction of plants with the environment, and the vital underlying acclimation and adaptation processes. The off-putting effects of abiotic stresses result in alteration in plant metabolism and physiology, which challenge survival, productivity, reproductive biology, and reproducibility. These adverse effects result from structural and functional alteration of cellular components of plant. Structural alterations of cellular organelles due to environmental stresses cause alteration in physiological processes, such as water entrance and transportation, nutrient uptake, chloroplast functioning, photosynthetic efficiency, mitochondrial activity, vacuolar structure and function, and the altered structure of nucleus cause genetic modification. The physiology and adaptive mechanisms of plants are greatly varied in different species and genotypes. The ability of various plant groups to tolerate the extremes posed by natural conditions and/or chemically rich environments involves morphological and physiological adaptation as well as changes in ecological behavior to sustain in relatively protected niches within an extreme environment.

To survive under environmental extremity, plants respond at the molecular, cellular, and physiological level, which involves a complex network supporting perception and transmission of stress signals, which subsequently initiate a plethora of responses. Against different kinds of stress-induced responses, there are two broad outcomes: programmed cell death (PCD) or stress acclimation. The PCD is considered a lethal effect whereas acclimation often leads to adaptation to certain adverse environmental stresses, which sustain plant survival and productivity. A deeper understanding of the mechanisms underpinning plant stress adaptation may offer novel opportunities to develop crop plants with an enhanced ability to tolerate environmental fluctuations, which are the focal points of concern of plant ecophysiological study. In modern concept, the survival mechanism and potential of plants are not left behind as a natural process. Rather how the adaptation process can be enhanced is a great concern of scientists of the related fields. In present perspectives, scientists are manipulating the surrounding environment of target plants so that the plant can be less affected by natural environmental stresses. Use of a broad range of exogenous phytoprotectants including plant nutrients, trace elements, phytohormones, and signaling molecules, probiotic microorganisms to improve adaptation processes of plants are being explored day by day. Scientists are going through the genetic manipulation and biotechnological processes to sustain plant productivity under the adverse environmental conditions. Much progress has been gained in the last few decades in the area of plant ecophysiology research and on their adaptive mechanisms. Although there are numerous publications in journal and proceedings, there is a scarcity of a comprehensive book dealing with both ecophysiology and adaptive mechanisms of plants under climate change.

This is the first volume of the two-volume book, *Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives* that provides current state-of-the-science knowledge of plant ecophysiology, with particular emphasis on adaptation to a changing environment. This volume will provide the reader with a wide spectrum of information, including vital references. This is done through 29 chapters written by hundreds of experts in the field of Botany, Plant physiology, Ecology, Crop science, and Environmental sciences, ultimately aiming to become a useful information tool for plant biologists, crop scientists, ecologists, plant breeders as well as a guide for students in the field of Plant Science, Agriculture and Environmental Sciences.

I like to give special thanks to the authors for their outstanding and timely work in producing such fine chapters. Our profound thanks also go to Mr. Sayed Mohammad Mohsin, Dr. M.H.M. Borhannuddin Bhuyan, Ms. Khurshida Parvin, Dr. Kamrun Nahar, Khussboo Rahman, Khadeja Sultana Sathi, and Mr. Abdul Awal Chowdhury Masud, for their critical review and valuable support in formatting and incorporating all editorial changes in the manuscripts. I am highly thankful to Ms. Lee, Mei Hann, Editor (Editor, Life Science), Springer, Japan, for her prompt responses during the acquisition. I am also thankful to Sivachandran Ravanan, Project Coordinator of this book, and all other editorial staffs for their precious help in formatting and incorporating editorial changes in the manuscripts.

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About the Editor

Mirza Hasanuzzaman is Professor of Agronomy at Sher-e-Bangla Agricultural University in Dhaka, Bangladesh. He received his PhD 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 MS 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 4800 citations with an h-index of 37 (As of April 2020). 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 Sciences Young Scientist Award (2014). He has attended and presented 25 papers at international conferences in many different countries (the USA, the 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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Chapter 1
Climate Change Influences the Interactive Effects of Simultaneous Impact of Abiotic and Biotic Stresses on Plants

Ewa Surówka, Marcin Rapacz, and Franciszek Janowiak

Contents

Since it is not feasible to formulate a comprehensive overview as the intricacy and immensity of the considered subject surpass the scope of this contribution, the chapter focuses on outlining the essential issues without an in-depth description of the underlying mechanisms.

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Abstract Under natural conditions, the defense responses of plants exposed to combined abiotic and biotic stress factors, which can randomly interact with each other, are in many aspects different from the response induced by an individual stress. Predicted climatic changes through affecting these simultaneously occurring interactions might change the microclimate surrounding plants, plants' susceptibility, the range of host microorganisms (i.e., symbionts or pathogens), and their simultaneous interaction with plants. The influence of climate change on interactions between environmental stresses and plants can lead to positive or negative impacts of one stress on the others and cause changes in strategies adopted by plants—either negative (i.e., susceptibility) or positive (i.e., tolerance)—thus causing modifications of primary and secondary metabolism of plants. Primary metabolism plays a key role in plants' adaptive/defense response through the influence on the modulation of secondary metabolism and the activation of the host's various defense mechanisms. Alterations in primary and secondary metabolism might include changes in the availability of nutrients, metabolically active compounds, or in carbon (C) and nitrogen (N) metabolism and C/N balance.

Keywords Climate change · C/N balance · Endophytes · Habitats · Holobiont · Invasive plants · Metaorganism · Microbiome · Rhizomicrobiome · Soil-plant-microbial interaction

Abbreviations

ACC deaminase	1-aminocyclopropane-1-carboxylate deaminase
AMF	Arbuscular mycorrhizal fungi
APSA	The Asia and Pacific Seed Association
Avr gene	Avirulence gene
CAM	Crassulacean acid metabolism
CC	Coiled-coil N-terminal domain
CCM	CO_2-concentrating mechanism
DAMPs	Damage-associated molecular patterns
eCO_2	Atmospheric CO_2 concentration
ET	Ethylene
ETI	Effector-triggered Immunity or R gene-mediated effector-triggered immunity
FAO	Food and Agriculture Organization of the United Nations
GCC	Global climate changes
GHG	Greenhouse gases
GLOBIO	Global Biodiversity model for policy support
HR	Hypersensitive response
IPCC	Intergovernmental Panel on Climate Change
ISR	Immune systemic resistance

ITPS	Intergovernmental Technical Panel on Soils
JA	Jasmonic acid
MAMPs	Microbial-associated molecular patterns
NB-LRR	Nucleotide binding (site)-leucine-rich repeat proteins
Oxfam	Oxford Committee for Famine Relief
Pacific ENSO	Pacific El Niño–Southern Oscillation
PAMPs	Pathogen-associated molecular patterns
PRRs	Membrane-bound pattern recognition receptors
PTI	PAMP-triggered immunity
SA	Salicylic acid
SAR	Systemic acquired resistance
TIR	Toll and interleukin-1 receptor type
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization
WUE	Water use efficiency

1.1 Introduction: Climate Change Alters Habitats and Affects Ecosystem Functioning

According to specialists' predictions, in the coming decades, alterations in the interactive effects of simultaneous impact of abiotic and biotic stresses on plants due to global climate changes delineated by UNFCCC seem unavoidable. Such prognoses are based on climate prediction models of IPCC indicating that average surface temperatures will rise by about 3–5 °C in the next 50–100 years, as well as that precipitation will increase by up to 1.0% for mid- and high-latitude areas and 0.3% for tropical zones (IPCC 2013, 2018; Christensen et al. 2013; Pachauri et al. 2014; Hoegh-Guldberg et al. 2018). The rising temperatures across the globe are caused by GHG of natural and anthropogenic origin, majority of which is atmospheric carbon dioxide (CO_2), indicated as showing a consistent, almost linear correlation between its cumulative emissions and projected global temperature. CO_2 concentration has surged by over 40% since the industrial revolution, and it is predicted to increase further up to 770 ppm in 2100 (compared to present concentration of around 400 ppm), while the level of 450 ppm of CO_2 [atm] has been suggested as a critical threshold which would cause an increase in the global mean temperature of 2 °C above preindustrial values (Ahanger et al. 2013; IPCC 2013; Mahato 2014; Pachauri et al. 2014; FAO and ITPS 2015; Lefevre et al. 2017; Challinor et al. 2018; Winkler 2019). The extent and intensity of climate-related factor changes (e.g., rising of atmospheric CO_2 level, atmospheric N deposition, elevated temperature, altered rainfall or moisture, pressure, light intensity) and the interactions among multifactorial stress combinations are predicted to increase in the next decades (IPCC 2013, 2018; Pachauri et al. 2014; Hoegh-Guldberg et al. 2018).

The consequences of climate variability lead to the creation of environmental change conditions—frequent and extreme weather phenomena such as heat waves, drought, salinity, alkaline/acid soils, floods, sea level rise, and ocean acidification. They will cause direct/indirect and positive/negative effects on living organisms such as alterations in species composition and range; species invasions and extinctions; phenology, biodiversity, and ecosystem regime shifts; as well as the generation of new interactions in novel communities, novel intra- and interspecies interactions among plants and microbial communities, and changed feedback processes which may in turn affect species dynamics and interactions and can lead to altered ecological processes and ecosystem functions (van der Putten et al. 2013; Classen et al. 2015; Ravichandran and Thangavelu 2017; Hassani et al. 2018; Hawkins and Crawford 2018; Hoegh-Guldberg et al. 2018; Winkler 2019).

Although the resistance of organisms and ecosystems is highly changeable, climate-dependent biological alterations are likely to be commensurately quick (Brierley and Kingsford 2009; Lee et al. 2009; Pachauri et al. 2014; Classen et al. 2015; Zhang and Sonnewald 2017; Cassia et al. 2018). It has been shown that climate change is already altering many wildlife habitats not only locally but also all over the world and some species and whole ecosystems have already been lost. Consequently, biological alterations from genes to whole ecosystems (including land and marine ecosystems) in most regions of the globe will continue to proceed (Hansen et al. 2007; Galland et al. 2012; Smith et al. 2015; Karmakar et al. 2016; Llado et al. 2017; Hutchins and Fu 2017; Makinen et al. 2017; Santoyo et al. 2017), though these changes are unpredictable as climate-related systems/factors are nonlinear (Lenton et al. 2008; Lenton 2012; Challinor et al. 2018).

Climate variations can lead to severely transformed ecosystems with new dominant species and new ways in which soil and organisms interact (van der Putten 2012; van der Putten et al. 2013; Classen et al. 2015; Ravichandran and Thangavelu 2017; Hassani et al. 2018; Hawkins and Crawford 2018). Global climate change could lead to irreversible or catastrophic consequences in ecosystems (Llado et al. 2017; Santoyo et al. 2017).

1.2 New Ecological Entities "Metaorganism" and "Holobiont"

Natural communities are composed of individual organisms (plants, animals, and microorganisms living in an environment determined by physical conditions/abiotic factors) interacting among themselves and composing a complete ecosystem. Every species shows multiple levels of organization across biological units. They are linked directly or indirectly with a multitude of other species through many different types of highly integrated functional interactions with beneficial, neutral, or harmful effects, and they exert a crucial influence on the functioning and health of individual species, communities, and whole ecosystems (Luttge 2012, 2013;

Matyssek and Luttge 2013; Souza and Luttge 2015; Mitter et al. 2016; Souza et al. 2016). Ecosystems as complex systems tend to show cyclic fluctuations around approximate equilibrium state and undergo inevitable and dynamic alterations when climate change occurs or when new species appear as a result of migration, evolution, or human activity (Classen et al. 2015; Vandenkoornhuyse et al. 2015; Luttge and Thellier 2016; Bang et al. 2018).

The interdependence between multi-organismic associations in the ecosystem, including (1) individual organisms showing a high degree of internal functional integration as well as (2) dynamic communities of microorganisms being an essential and vital part of the functionalities of individual organisms or the whole ecosystem, is often established through their coexistence in ecological and evolutionary dimensions. This view led to the creation of the concept of a metaorganism (Bosch and McFall-Ngai 2011; McFall-Ngai et al. 2013; Vandenkoornhuyse et al. 2015; de Souza and Fiocchi 2016; Theis et al. 2016; Bang et al. 2018; Morris 2018; zu Castell et al. 2019). Multi-organismic cooperation which comprises a host organism (i.e., different plant tissues/organs and plant seeds) and its specific endocellular and extracellular associated microbiome (e.g., viruses, phages, eubacteria, archaea, fungi, protozoa) has been termed a holobiont (Mendes et al. 2013; Castell et al. 2016; Mitter et al. 2016; Smith and Dukes 2017; Morris 2018; Rosenberg and Zilber-Rosenberg 2018; Ying-Ning et al. 2017; zu Castell et al. 2019) and can function as an actual platform of selection and coevolution (anatomically, metabolically, immunologically, or developmentally) (Vandenkoornhuyse et al. 2015; Fladung 2016; Rosenberg and Zilber-Rosenberg 2018). The health and oftentimes the survival of the majority of holobionts depend on the network of interactions between all of their members (Mitter et al. 2016; Carrier and Reitzel 2017; Rosenberg and Zilber-Rosenberg 2018). Holobiont is represented by its hologenome consisting of two complementary components, host genome—highly conserved and microbiome genome—dynamic and effectively and rapidly changing, in response to environmental conditions, which might be selected for or against, thus enabling the promotion of acclimation and adaptation to changing environmental conditions (Berg et al. 2014; Souza and Luttge 2015; Larranaga and Ignacio Hormaza 2016; Souza et al. 2016; Rosenberg and Zilber-Rosenberg 2018; zu Castell et al. 2019). Thus, plant adaptation through genetic accommodation includes the variability of both mutualist-induced and epigenetically induced plasticity in the holobiont. Genetic accommodation and adaptation can impact both plant genome and all components of the holobiome, including genetic variability of microbiota, and is related to the occurrence of phenotypic variation induced by mutualists (Vannier et al. 2015; Carrier and Reitzel 2017; Ilangumaran et al. 2018). The evolutionarily advantageous development of relationships and cooperation among the components of the holobiont makes it possible to withstand environmental challenges (Smith and Dukes 2017; Ilangumaran et al. 2018). However, it should be noted that it is still under discussion whether metaorganisms constitute a hologenome as a unit of selection or whether they consist of separate entities which evolve independently (Carrier and Reitzel 2017).

1.3 Climate Change Affects Natural Habitats and Biodiversity of Plants and Microorganisms

The nature and type of vegetation are related to the availability of habitats, which are determined by latitudes and environmental factors (e.g., soil, light intensity, temperature, climate cycles). It is well established that with increasing latitudes, natural resources change, causing a decline of functional diversity of individual organisms, population, species, community, ecosystem, and biome scales (Rohde 1992; Cong et al. 2016). Additionally, rapid climate changes are anticipated to affect all the levels of biodiversity (decline or increase), from organism to biome levels (Sax and Gaines 2003; Dornelas et al. 2014; McGill et al. 2015; Gonzalez et al. 2016). As a consequence of the processes of biome or ecosystem degradation, the disruption of natural plant communities often coincides with or is preceded by a loss of physicochemical and biological soil properties.

1.3.1 Physicochemical Soil Properties

Soil is an integral structural part of every terrestrial ecosystem, substantially influencing biomes. Soil plays many important functions such as (1) affecting water quantity and quality; (2) providing water and nutrients, and functioning as a terrestrial regulator of carbon (C) and nitrogen (N) cycles according to the new climate regime established by the Paris Agreement of December 2015; (3) allowing an exchange of CO_2, oxygen, and other gasses (including GHG) which affect root growth and soil organisms; (4) providing physical support for plant vegetation and supporting a wide diversity of microbial, flora, and fauna taxa; (5) providing a substrate for organisms linked with vital ecosystem processes; and (6) influencing the harboring of root diseases and other pests (Makinen et al. 2017; Santoyo et al. 2017). The nature of soil habitats is affected by a complex interplay of direct and indirect interactions among soil properties.

The key potential changes in soil-forming factors and/or disturbances in the complex interplay of environmental factors that directly result from GCC could be in organic matter supply from biomass and the quality and quantity of resource input, alteration in the dominant soil type, and essential physicochemical soil properties (e.g., pH value, soil temperature regime, soil hydrology, the range of equilibrated mineral nutrient cycles/mineral nutrient limitations) (Smith et al. 2015; Karmakar et al. 2016; Llado et al. 2017; Makinen et al. 2017; Santoyo et al. 2017).

1.3.2 Soil Influence on Microbiota and Plant Diversity

It is well established that soil physicochemical properties, including soil pH, which is the master variable, affect many properties of the ecosystem, e.g., through changes in microorganism habitats and microorganism species composition such as bacteria, actinomycetes, fungi, algae, and protozoa in different physiological states (Blagodatskaya and Kuzyakov 2013; Lian et al. 2019; Tripathi et al. 2018) or through alterations in biomass or activities of soil microbial communities as well as microbial interactions like competition for resources including C and N (Balser et al. 2002; Wardle et al. 2006; van der Putten et al. 2007a; Raizada et al. 2008; Rengel 2011; Bach et al. 2018; Maron et al. 2018; Quatrini and Johnson 2018; Tripathi et al. 2018). A typical gram of soil has been suggested to contain about 9×10^7 bacteria, 2×10^5 fungi, 4×10^6 actinomycetes, 3×10^1 nematodes, 5×10^3 protozoa, and 3×10^4 algae. It has also been shown that soil pH plays an important role in bacterial and fungal growth and microbial biomass and composition and that most bacteria prefer nonacid microhabitats (Rousk et al. 2009; Ravichandran and Thangavelu 2017; Bach et al. 2018). The total microbial biomass is usually estimated at 50–2000 μg C g^{-1} soil, and this is about 2–3% up to/not exceeding 4.5% of organic C content (Blagodatskaya and Kuzyakov 2013), and 10 g of soil holds about 10^{10} bacterial cells, representing upward of 10^6 species (Gans et al. 2005; Schloss and Handelsman 2006). According to Wang et al. (2017), healthy soils, when compared to infected soils, exhibit both higher diversity and content of beneficial microorganisms promoting plant growth as well as preventing plant diseases. Moreover, soil pH also affects soil enzyme activity, which may influence litter decomposition and alter soil nutrient availability (especially pools of C, N, and phosphorus (P)), dynamics of carbon and nitrogen cycles, ionic composition of soil solution, and aeration capacity (Sardans and Penuelas 2015; Ravichandran and Thangavelu 2017). Also, the richness and distribution of plant species are determined by soil physicochemical properties, particularly soil pH values (Gough et al. 2000; Cong et al. 2016; Llado et al. 2017).

In addition, Hou et al. (2018) estimated that climate change affects soil phosphorus cycle and the availability of P in global land ecosystems. It has been shown that soil-available PI, indexed by Hedley labile inorganic P fraction, fell significantly with rising mean annual temperature and rainfall. Authors also postulate that temperature and rainfall have opposite effects on soil P availability and can interact with soil particle size to regulate it. Although P is essential in plant nutrition, only 0.1% of total P in the soil is accessible to plants, making P the chief bottleneck for plant growth (Sharma et al. 2013). Thus, the changes in the availability of P can impact plants and related microbiota distribution.

Furthermore, climate change influences nitrogen cycle (Conniff 2017). According to the author, atmospheric N originating from intensive human activity and other sources is moved to the water and also lands/soils via a process called N deposition. Deposition of N has increased tenfold or more since preindustrial times and makes soils more fertile, leading to the contradictory effect of diminishing plant diversity by supplanting native species accustomed to nutrient-poor soils. For instance, across the United States upon investigating upward of 15,000 forest, woodland, grassland, and shrub land sites, it has been found that a quarter of them have already exceeded the N levels accompanying species loss. Moreover, a study in an arid South California habitat has revealed that N supplementation together with altering precipitation patterns brought about a shift from native shrubs to non-native grasses (Simkin et al. 2016; Conniff 2017; Gilliam 2019). Also, another series of recent studies showed that many European ecosystems were experiencing reductions in plant biodiversity due to N deposition (Dise et al. 2011; Payne et al. 2017). According to Lebeis (2015), nitrogen pool and its availability are affected more strongly by the environment than plants.

1.3.3 The Role of Microbiota in Habitat Modulation

Microbial communities, including bacteria and fungus species, in response to environmental changes modulate soil quality and properties such as soil pH, temperature, and relative humidity (Nannipieri 2006; Rousk et al. 2009; Ravichandran and Thangavelu 2017). Soil microbes are involved in (1) constant flow of low- and high-molecular-weight plant-derived organic compounds, (2) many biogeochemical processes (e.g., water or nutrient cycles), and (3) decomposition of organic matter (Herman et al. 2012; de Vries and Caruso 2016) and in the biological conversion of various nutrient pools, including carbon (Rumpel et al. 2015; Quiza et al. 2015; Legay et al. 2016; Okubo et al. 2016; Wang et al. 2017; Mandakovic et al. 2018).

Some soil microorganisms, mainly bacteria such as *Acidobacteria* or *Aciditerrimonas*, are associated with soil acidification and disease, while high abundance in the soil of advantageous microbes—such as *Agromyces*, *Acremonium*, *Bacillus*, *Bradyrhizobium*, *Chaetomium*, *Lysobacter*, *Micromonospora*, *Mesorhizobium*, *Microvirga*, and *Pseudonocardia*—is positively correlated with soil fertility and health (Unterseher et al. 2013; Purahong et al. 2016; Wang et al. 2017). Beneficial soil microbes play a role in preventing erosion, stabilizing soil aggregates, decomposing organic residues, solubilizing mineral phosphate, fixing atmospheric N, and improving nutrient cycling as well as in suppression of plant diseases and soil-borne pathogens (Quiza et al. 2015; Talaat and Shawky 2017). Also, microbial enzymes released into the soil, water, or plant microenvironments may affect biogeochemical processes (Nannipieri et al. 2012; Schimel and Schaeffer 2012; Alves et al. 2014; Khare and Yadav 2017). Thus, the altered belowground processes and the newly established interactions among soil microbiota due to climate change can have an immense influence on nutrient re-translocation within the ecosystem (Ehrenfeld 2003), especially the turnover of C and N pools (Balser et al. 2002; Gonzalez Megias and Mueller 2010; Reidinger et al. 2012; Brunner et al. 2015; Classen et al. 2015; Godschalx et al. 2015; Dawson and Schrama 2016; Ryalls et al. 2016; Heinen et al. 2018a, b; Agrawal et al. 2018; Maron et al. 2018; Ourry et al. 2018).

1.3.4 The Role of Plants in Modulation of Habitats

Plants, including invasive species, influence soil properties (Ehrenfeld 2003; ISAC 2006; Cong et al. 2016; Ravichandran and Thangavelu 2017). For example, *Wedelia trilobata* caused a significant rise in soil pH values at low levels of invasion, whereas high levels of invasion had no impact on soil pH values (Si et al. 2013). Other plants such as *Ambrosia artemisiifolia* L. (Li et al. 2014), *Solidago gigantea* (Herr et al. 2007), and *Lepidium latifolium* (Blank and Youn 2002) at an increased intensity of invasion caused a decrease of soil pH compared to sites of native plants. According to the authors, decreased soil pH values caused increased solubility of nutrients, e.g., P, and their higher availability for plants. Enhanced nitrification was proposed as a likely explanation for decreased pH under the invasion of *Berberis thunbergii* and *Microstegium vimineum* (Ehrenfeld and Scott 2001; Ehrenfeld 2003). Soil acidification during the invasion of *Avena barbata* and *Bromus hordeaceus* has a disadvantageous influence on the concentration of soil nitrate but an advantageous one on the concentration of soil ammonium (Hawkes et al. 2005). As discussed by Novoa et al. (2014) and Maron et al. (2018), the initial characteristics of the invaded ecosystems, including plants and microorganism community, play a key role.

1.4 Global Climate Change Affects Diversity of Plants and Microbiota and Interactions in Ecosystems

Apart from the influence of climate change on soil properties and natural resources including cycles of carbon and nitrogen, microelements pools, climate change modifies also microorganism communities essential for global nutrient cycling, plant biodiversity, as well as the network of close interactions between the soil, plants, and soil microorganisms (Fig. 1.1), which can occur as both native and non-native in the ecosystem (Ravichandran and Thangavelu 2017; Cowan et al. 2018; Sielaff et al. 2018). Microorganisms coexisting in nature are also engaged in intricate interactions with other organisms and their surroundings. These interactions, based among others on the exchange of electron donors or processes of auxotrophies, can affect community activities and composition (Zengler and Zaramela 2018). The altered close connections between different microbial communities occurring in varied habitats, e.g., in the soil, or in plant organs are likely to affect plant fitness, adaptability in natural systems, biodiversity, or the evolutionary path of individual species and whole ecosystems (Dai et al. 2016; Coats and Rumpho 2014; Maron et al. 2018; Zhang et al. 2018).

Changed levels of critical macro- and micronutrients (including C, N, P) due to climate change can cause modification of microbial community. It has been shown that bacteria and fungal communities correlate with microhabitats and specific soil geochemical features and play a distinct role in major nutrient cycles, though they both—bacteria and fungi—show differences in shaping C and N distribution in the soil (Mueller et al. 2015; Sun 2018).

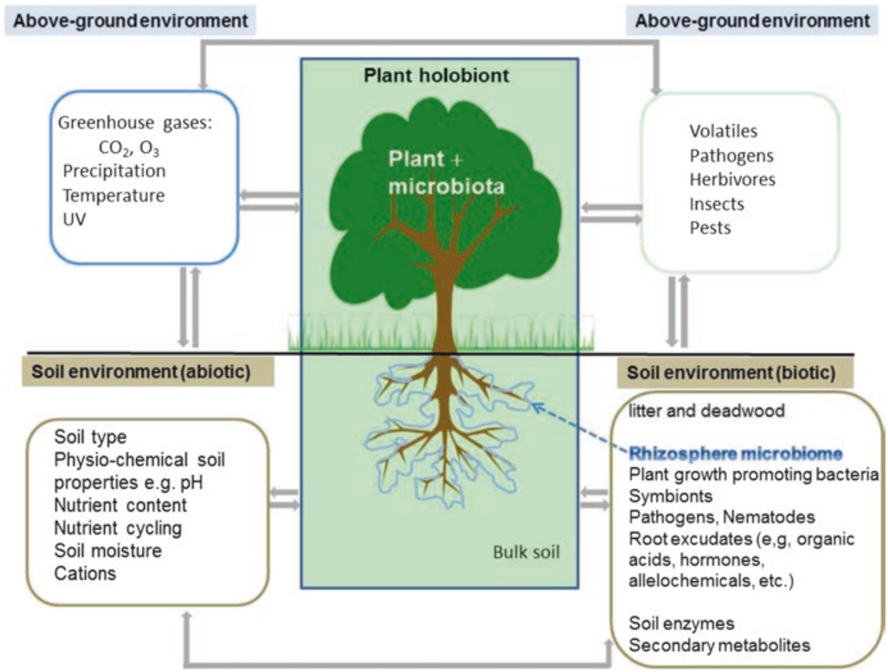

Fig. 1.1 The relationship between plant habitat and the ecosystem

Among different interactions in the ecosystem that can be affected by climate change, an important role is played by plant–soil microbiota feedback known as plant species-dependent profile of belowground microbiota, which in turn impacts the functioning of other plants growing subsequently in the same soil (van der Putten et al. 2013; Ravichandran and Thangavelu 2017; Heinen et al. 2018a, b). It has been shown that the feedback which influences plants via nutrient availability and changed microbiota both beneficially and pathogenically running the whole gamut of ecological possibilities (e.g., competitive, exploitative, neutral, commensal, mutualistic) can cause the establishment of new interactions between plants and belowground biotas, especially in the rhizosphere (Chakraborty 2005; Ruppel et al. 2013; Zhang and Sonnewald 2017; Bach et al. 2018; Jansson and Hofmockel 2018). Moreover, the responses of some organisms to climate change may affect microorganisms and plants that depend on them (Bellard et al. 2012; Montoya et al. 2012; Ravichandran and Thangavelu 2017). Plant species-mediated processes and plant interactions with microorganism community can further modify soil properties and biodiversity of plants (Kourtev et al. 2002; Yang et al. 2013; Li et al. 2014; Qin et al. 2014; Dawson and Schrama 2016; Ravichandran and Thangavelu 2017) as well as alter below- and aboveground organisms (Kos et al. 2015a, b; Heinen et al. 2018a, b) such as endophyte microbiomes colonizing root and shoot tissues (Wardle 2002; Wang et al. 2007, 2017; Zhang and Sonnewald 2017; Garcia and Kao-Kniffin 2018; Heinen et al. 2018a, b; Tripathi et al. 2018), insects, or herbivores (Brunner et al. 2015;