Mohd Sayeed Akhtar *Editor*

Salt Stress, Microbes, and Plant Interactions: Causes and Solution

Volume 1

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This book is dedicated to my grandfather (Dada)

S. Allauddin (1926–1970)

A great visionary, statesman, philosopher, and social reformer of the twentieth century and legendry icon of my life

Foreword

Stressful environments affect not only our soils but also crop productivity. We are in a great need of eco-friendly alternatives for saving our environment. Consequences of the on-going rise in human population, dramatic change in global climate, shrinking agricultural lands, rapid urbanization, and extensive use of agrochemicals are collectively affecting global crop production. In addition to these, climate change is another challenging issue confronting us currently. An excessive and deliberate use of chemicals in our agricultural systems necessitates to look for safe paths. Although we know much about the fact how soil biota can influence physiological responses of plants in particular salt stress, the microbial life in our soils makes it difficult for us to be sure about the importance of particular mechanisms in these interactions in different environments. Any kind of stress serves as the prime factor for limiting agroproductivity. There is an acclimatization under stress conditions originating from the ecological conditions of a species; stress deteriorates the biological mechanisms which growth and productivity endure. Among various types of stresses, abiotic stress is the major cause, limiting global crop productivity; however, the effects on the plant depend on its quantity or intensity; heat, cold, drought, alkaline conditions/salinity, waterlogging, light intensity, and nutrient deficiency are the different types of abiotic stresses. More than three billion ha of drylands are influenced by soil erosion, degradation, and salt stress. Plants possess several defense mechanisms to face such stressful conditions. One of these are the microbes, the supreme natural occupants of different environments with varying physiological and metabolic mechanisms to manage environmental stresses.

The interactions of microbial population with plants are essential for the ecosystem in order to combat with stressful environment. It is becoming more important to characterize and enlighten plant-microbe associations in relation to defense against environmental challenges. Although some beneficial effects of soil biota on the plants found on saline soils is well known, many underlying physiological and molecular mechanisms need to be identified in order to optimize the agronomic applications of soil microorganisms. A better understanding of the different mechanisms involved in plant-microbe and microbe-microbe interactions is a prerequisite for developing new strategies for improving crop yields. These beneficial microorganisms can be used as efficient bioagents in the management of stressed agriculture. Their role in improving nutrient availability to plants seems as an important strategy and related to climate-smart agricultural practices. Majority of the vascular plants form symbiotic associations with mycorrhizal fungi, and many beneficial interactions have been reported. Microbes improve the efficiency of applied fertilizers and manure. Land use changes and the associated loss of beneficial microbial diversity are the major reasons for deterioration of soil fertility and agricultural productivity.

This book *Salt Stress, Microbes and Plant Interactions: Causes and Solution (Volume 1)* to be published by Springer includes 13 chapters. Chapter 1 deals with the challenges regarding agroecosystems. Among these, soil salinity is mentioned as one of the most devastating environmental stresses, which causes major reductions in cultivated land area, crop productivity, and quality. The authors discuss the causes of soil salinity and its impact on crop production due to increasing farming costs under saline soils. They are focussing on the past and present studies on salinity and its economic impact on agricultural system. Chapter 2 presents an overview on the potentiality of plant growth-promoting rhizobacteria in easing of soil salinity and environmental sustainability. In Chapter 3, the use of plant hormones for the improvement of plant growth and production under salt stress has been presented with data from Pakistan. It summarizes the role of hormones such as abscisic acid, cytokinins, gibberellic acid, brassinosteroids, salicylic acid, and jasmonates for improving plant's tolerance and productivity under saline conditions. Chapter 4 deals with the plant growth regulators and salt stress: mechanism of tolerance tradeoff with studies from India. The authors are pointing out that in order to improve salt stress tolerance, some sustainable strategies should be chalked out which on one hand engineer salt tolerance and on the other side improve growth, photosynthesis, and yield of plants. They are highlighting the role of PGRs for engineering tolerance against salt stress in various crop plants, together with underlying mechanisms by which plants perceive signals of stress which trigger signal transduction cascades. Chapter 5 focuses on the impact of plant-microbe interactions on plant metabolism under saline environment and also on the involved mechanisms. In Chapter 6, Indian authors entail the plant survival and tolerance under high salinity and also highlighted the primary and secondary cell wall sensing mechanism during salinity stress. However, Chapter 7 presents the results related to the field application of rhizobial inoculants in acidic soils with a case study from Ethiopia. It reviews the field application of faba bean rhizobial inoculants in acidic soils as a promising potential input in organic farming system, highlighting the physiological and molecular events involved in the response and tolerance to soil acidity in legumes, rhizobia, and *Rhizobium*–legume symbiosis. Chapter 8 by Indian investigators discusses the knowledge of heavy metal toxicity, and its remediation using microbes, and also highlighted the utilization of soil microbes for combating the heavy metal stress in plants, while Chapter 9 significantly articulates the use of nanoparticles in alleviating salt stress. Chapter 10 deals with the interaction of soil, plant, and microbes in improving salt stress conditions. However, Chap. 11 emphasizes the mitigation of salinity stresses in the plants through mycorrhizal association. Chapter 12 is titled as "Halophilic Microbe Interactions with Plants to Mitigate Salt Stress" with case study from India. It enlightens the facts related to the use of halophilic plant growth-promoting microbial inoculants in the form of bio-formulations which have future application for the rehabilitation and bioremediation of saline degraded lands, while salinity imbalance and soil nutritional and microbial status on the plant health are summarized in Chap. 13. This volume includes detailed knowledge on salt stress, plant, and microbe interactions with a stress on agronomic, molecular, and ecological approaches. It will open the way for new discussions and efforts to the use of various tools for the improvement of crops under such conditions. I personally congratulate Dr. Mohd Sayeed Akhtar for their noble academic effort in bringing out this volume

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Izmir, Turkey

Preface

Salt stress has pessimistic crash on the yields of various agricultural crops, and it may directly affect the livelihood of farmers worldwide. The excessive salts in soil lower the availability of water, inhibit metabolic processes, and affect nutrient composition, osmotic balance, and hydraulic conductivity that result to stunted growth and low productivity of cultivated crop plants. Plants have developed number of processes involved in the tolerance mechanism, such as various compatible solutes, polyamines, reactive oxygen species and antioxidant defense mechanisms, ion transport, and compartmentalization of injurious ions. To overcome this problem, exploitation of genetic variation; use of plant hormones, mineral nutrients, and soil microbes; and other mechanical practices are of prime importance. It is a fascinating subject, which is multidisciplinary in nature, and concerns scientists involved in plant heath. There have been marked advances in this field during the past few decades.

Salt Stress, Microbes and Plant Interactions: Causes and Solution (Volume 1) incorporates both theoretical and practical aspects and may serve as baseline information at physiological, ecological, biochemical, environmental, and molecular levels for future research through which significant developments can be expected. I hope that this book is helpful for the students, teachers, researchers, and industry persons who are interested in agronomy, ecology, stress physiology, environmental science, crop science, and molecular biology.

I am highly grateful to all our contributors for readily accepting our invitation, for not only sharing their knowledge and research but venerably integrating their expertise in dispersed information from diverse fields in composing the chapters, and for enduring the editorial suggestions to finally produce this venture. I greatly appreciate their commitment. I am also thankful to Professor Munir Ozturk for his suggestion and writing the foreword for this volume. Moreover, I am thankful to my beloved wife, Mrs. Shagufta Bano, and lovely sons, Mohd. Rafaan and Mohd. Almaan, for their unconditional encouragement, support, and moral boost up throughout the compilation of this book volume. I also thank the team of Springer Nature, especially Dr. Kapila Mamta, Raman Shukla, and Raagaipriya Chandrasekaran, for their generous cooperation at every stage of the publication.

Shahjahanpur, Uttar Pradesh, India Mohd Sayeed Akhtar

About the Book

The interaction between plant, soil, and microbes is fairly intricate and is essential for combating any stressful condition. The presence of excessive salt in soil lowers the availability of water, inhibits metabolic processes, and affects nutrient composition, osmotic balance, and hydraulic conductivity that resulted in the stunted growth and lower productivity of crop plants. *Salt Stress, Microbes and Plant Interactions: Causes and Solution (Volume 1),* along with the forthcoming *Salt Stress, Microbes and Plant Interactions: Mechanisms and Molecular Approaches (Volume 2)*, provides a detail account on the physiological, ecological, biochemical, environmental, and molecular levels for this multi-tropic interaction. Specifically, these two titles focus on both the theoretical and practical aspects and also provide a solid foundation for students, teachers, researchers, and industry persons interested in agronomy, ecology, stress physiology, environmental science, crop science, and molecular physiology.

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About the Editor

Mohd Sayeed Akhtar (PhD) is working as an assistant professor in Gandhi Faiz-e-Aam College, Shahjahanpur, UP, India. He has received his PhD degree from Aligarh Muslim University (AMU), India, in 2008, prior to conducting postdoctoral research at the Botanical Institute, University of Basel (BIB), Switzerland, in 2008–2010, and Chonbuk National University (CBNU), Republic of Korea, in 2011. He was an assistant professor at Jimma University, Ethiopia (2011–2014), and a fellow researcher at the Institute of Tropical Agriculture, Universiti Putra Malaysia (UPM) (2014–2015). He has more than 15 years of research and 10 years of teaching experience in soil microbiology, applied microbiology, environmental microbiology, molecular biology, plant pathology, and plant nanobiotechnology. He is author and coauthor of more than hundred articles in peer-reviewed journals, conference proceedings, and book chapters and has edited 12 books with international publishers. He is serving the scientific community as editorial board member and reviewer of several high-impact international journals. His current research is focused on the rhizospheric plant-microbe interactions and their molecular biotechnology, bioremediation, biomineralization, nano-fertilizers, and nanobiotechnology.

Global Concern for Salinity on Various Agro-Ecosystems

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Ghulam Mustafa, Mohd Sayeed Akhtar, and Rabia Abdullah

Abstract

Twenty-first century is marked by many challenges regarding agro-ecosystems, such as environmental pollutions, scarcity of water, and increased salinization of soil and water. Population bomb (increasing human population) and reduction in land available for cultivation are two threats to agricultural sustainability. In this situation, demand for cultivable land increases. However, environmental degradation factors such as erratic rainfall, extreme temperatures, drought and floods, high winds, and soil salinity have affected the production and cultivation of agricultural crops. Among these, soil salinity is one of the most devastating environmental stresses, which causes major reductions in cultivated land areas, crop productivity, and quality. Soil salinity further impacts the general public, particularly farmers, through its effect on agriculture. Therefore, it is necessary to find the causes of soil salinity and its impact (economic and environmental) on crop production in saline soils given the increasing farming costs. Thus, the main focus of the present chapter is to provide an overview of the past and present studies on salinity and its economic impact on the agricultural system.

Keywords

Agro-ecosystems · Economic analysis · Environmental impact · Salinization · Salt stress

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1.1 Introduction

Soil salinity is described as any collection of soluble salts that may be injurious to plants (Machado and Serralheiro 2017). It is the chief restrictive factor that threatens the capability of agricultural crops to meet the demands of the increasing human population. Saline soil contains the salt such as sulfate and chloride of Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K) (Zaman et al. 2002). Salinity is of major concern in moist areas, and it happens certainly only in coastal areas, depending on sea water imposition or flooding. Moreover, exhaustive fertilization adds insult to injury and causes flooded lands more saline. Additional problems of salinity arise due to increase in supplemented irrigation in humid areas in barren and semiarid regions. For plants, it becomes problematic to extract water from the soil due to the high concentration of soluble salt. Higher level of salt concentrations can be formed due to poor irrigation system, soil drainage, and high level of salt concentrations in irrigation water and unnecessary utilization of manure or dung as fertilizer. Using high salt-concentrated water can affect mostly irrigated areas (salinization). According to an estimate, about 831 million ha of land is affected by salt, which consists of ~7% of the total land in the whole world (FAO 2015).

Management practices regarding soil and waterfor sustainable agriculture production have demoted due to soil salinity. Marginal gains from such management practices also reduce due to saline soil. One of the major factors restricting the production of major crops in the whole world is impacted soil. For the projected population till 2050, a substantial amount of (50%), wheat, rice, and maize is needed to satisfy food demand. The pressure of sustaining the increasing world population has become necessary through soil and plant productivity research. Although resisting salinization, soil pollution and desertification are the major hurdle for sustainablity world population. Under this situation, appropriate biotechnology is expected, which not only expands the productivity of crops but also enhances health of soil via connections of plant roots and soil micro-organisms. Thus, the main focus of the present chapter is to provide an overview of the past and present studies on salinity and its economic impact on agricultural systems.

1.2 Human Population Growth and Agriculture Challenges in the Twenty-First Century

Thomas Malthus (1806) introduced the issue on food security and proposed the hypothesis that increasing global population will ultimately impede the Earth's ability to feed it. "The power of population is indefinitely greater than the power in the earth to produce subsistence for man" (Malthus 1806). This Malthus theory was expanded by Ehrlich, declaring that humans would fail against the battle of hunger. Regardless of Ehrlich's assumptions, it is identified that some social changes have already been appearing that reveal that in some populations, the process of growth is slowing. For example, in most developed nations, the Green Revolution has had greater effect than predicted, and productivity rates have fallen to less than replacement levels (Ehrlich and Ehrlich 2009). The most important challenge that agriculture is facing now is the ability to produce enough amount of food to meet the demands of the growing global population. The world population is likely to reach 10 billion by 2059, which means greater demand for agricultural production. Presently, worldwide population growth is decelerating, but after 2050 and in the succeeding era, population will tend to grow in some areas. With the increase in population, people prefer to live in urban areas than in rural areas. This trend of urbanization has implications on the food system. Scenarios of population growth in different decades is estimated by the United Nations Population Division in three contexts: high, medium, and low alternates. Anticipated variations in these alternates are shown in Fig. 1.1, in which medium alternate is used as reference.

Figure 1.1 shows that nearly in the past years, the annual growth rate of the global population is decreasing. In the peak period of 1960, world population growth rate was 2% per annum with total fertility rate (TFR) of 4.5. In 2015, with the decrease in TFR to 2.5, the growth rate of the global population also decreased 1.2% annually. Meanwhile, absolute annual increments have been increased regardless of the fact that population growth is decreasing. Recently, absolute annual increment is lower than 80 million people.

Absolute increments in medium alternative tend to decrease gradually 55 million people in 2050 and by the end of the century 15 million reductions would be there per year. These increments, cumulatively, will leave 9.73 billion of world population in 2050 and 11.2 billion in 2100 (Fig. 1.2). Among low-income, middle-income and high-income regions these universal tendencies are substantially different. In middle- and low-income countries, population growth will decrease in the medium and even long run, whereas over the period up to 2040, high-income countries will reach their maximum population size. Even in low-income countries, population growth rates will also significantly differ. Figure 1.3 illustrates that in between 2050 and 2060, the higher-populated continent, Asia, would attain its population peak. In East Asia, sustained and increasing growth rates are expected, but after 2040, population growth will decline. After 2070 South Asia will reach at its population peak and it will suffer after that peak point. Population growth is likely slow in Latin America, and this area will not attain its maximum population size during the estimated period up to 2060. After 2080, sudden and more robust progress is predictable for North and East Africa areas. It is estimated that global population growth will continuously increase to 11.2 billion people by 2100.

For many eras, people had lived chiefly in rural places. Thirty-five years ago, more than 60% of the population lived in rural areas. Thereafter, this rural trend changed tremendously, and now more than half (54%) of the world's population is living in urban areas. For the period up to 2050, more than two thirds of the people might be living in urban zones (UN 2015). Agricultural changes due to technical progress and labor-saving techniques aided to meet the food demands of urbanization. But at the same time, urbanization has a great impact on agriculture, nutrition and food.

In developing countries, urbanization is surging in similar numbers. Urbanization has great implications on the food system. It is projected that in

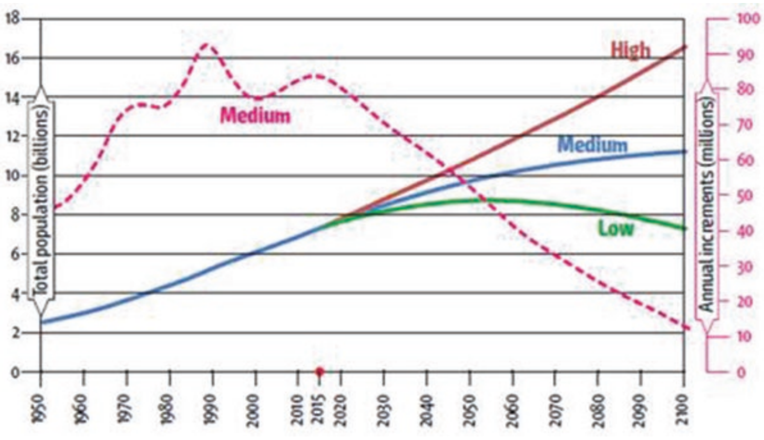

Fig. 1.1 Global population growth up to 2100, by variant

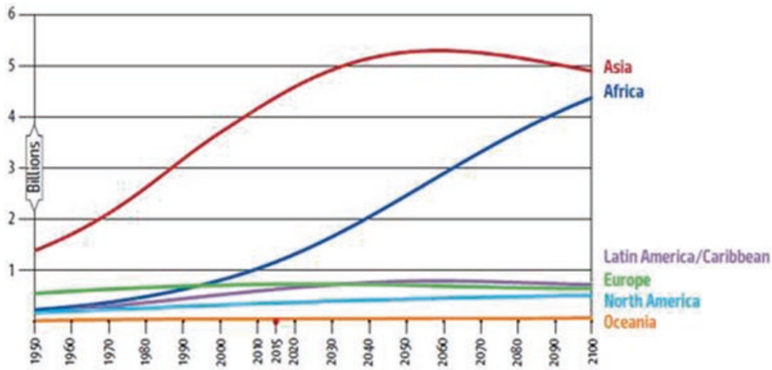

Fig. 1.2 Population growth up to 2100, by region (Medium variant)

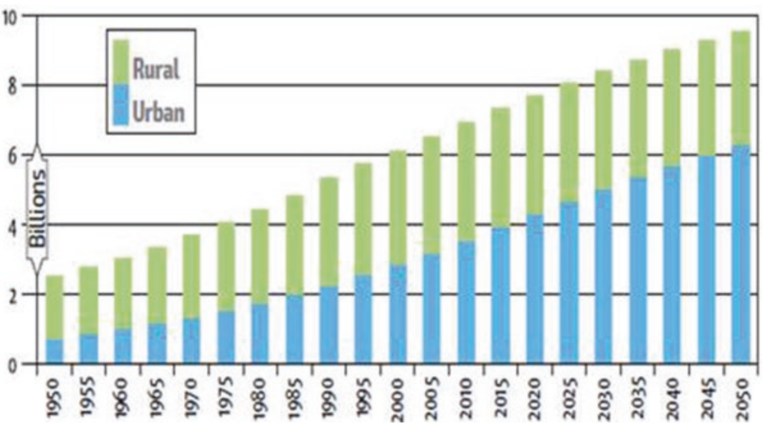

Fig. 1.3 Growth in global urban and rural population up to 2050

rural areas, people would get 60% of their food from their own produce, and the rest they would purchase from the market. However, people in rural areas now purchase 90% of their food from the market. Thus, when one person would migrate from a rural area to an urban one, a twofold increase in food supply will be required. Now the question is where this food will come from in order to meet the demand of the people. Trade expansion would not be the exact measure, seeing the trend in the last 50 years. In late 1960s, the production of global grains more than doubled, so the trade for grains also doubled. Therefore, the traded share of global grain consumption stayed fixed at almost 10%. It means that the majore global grain production (about 90%) would be consumed in the same producing country. If this tendency remains same the countries of high population growth rate would be the drivers to increase food production system. From 2000 to 2030, population will rise in the Tropic of Cancer and Tropic of Capricorn areas and will even undergo speedy population growth. Due to these facts, it is recommended that, in the next 25 years, tropical and subtropical systems of farming be used to produce enough food to fulfill the increasing demand of the population. However, these farming systems in tropical and subtropical areas are highly assorted, difficult, low in productivity, unstable and subjected by small scale poor farmers.

During the Green Revolution, the use of more land for productivity, irrigation, and agricultural chemicals performed a key roles in the evolution of agricultural production. But, now, it is identified that extensive use of lands for more productions put frequently negative impacts on natural resources of agriculture containing irrigated areas' salinization, land degradation, over eradication of ground water, ablation of biodiversity and increase of pest resistance. Agriculture also caused other damages to the environment because of the emission of greenhouse gases, deforestation, and water pollution (FAO 2011a). Figure 1.4 indicates that in the 1990s, at the world level, average growth in the production of rice, wheat, and maize has been only 1% lower than in the 1960s, whereas sugarcane and soybean production remains below 1%. Since the extra quantities of food will be required in this century due to high polpulation growth. This extra food will be produced chiefly by increasing yield rather than expansion of cultivated areas. Ceral productivity growth rate is lower than one percent and this would be a worrying indication if the growth rate will not be increased. Moreover, in low-income and high-income countries, there is a great variation in the yield of crops. In low-income countries, the productivity of rice and wheat is presently about half of that of their counterparts, while productivity of major crops also considerably varies across the areas. More than 50% gaps of potential productivity is estimated in the low-income countries and this gap is largest (76%) in sub Saharan Africa and lower (11%) in East Asia. The farm productivity gaps lead to constraints such as an inadequate adaptation of more productive technologies, lack of market integration in small-scale family farming and gender inequalities (FAO 2011b). In agriculture, gender inequalities are high where females are underpaid (Sen 1999). This is due to the constraints emerged from farm productivity gaps. Thus, the challenge of food productivity is not so simple; it requires the maximum

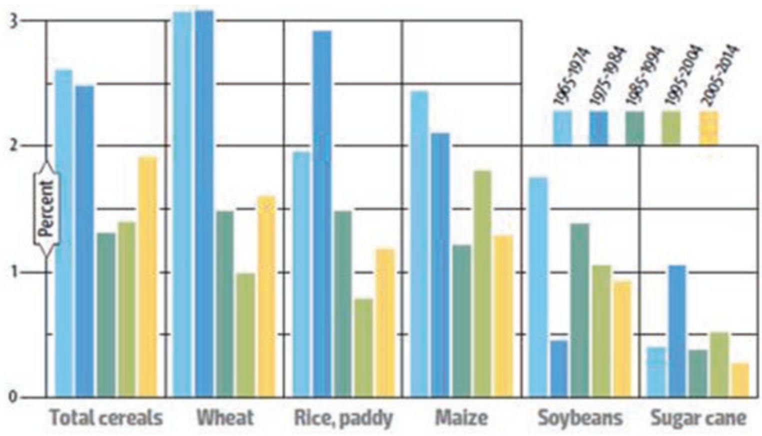

Fig. 1.4 Average annual growth rate for selected crop yields

productivity of complicated and low-producing land in a manner that would not deplete the physical environment and natural resources.

1.3 Global Concern About Soil Salinity

The beginning of the twenty-first century has been marked by global challenges of environmental pollution, water resource scarcity, and augmented salinization of soil and water. There are two main threats for agricultural sustainability: growing human population and lack of land for cultivation (Shahbaz and Ashraf 2013). It has been assessed that globally 33% of irrigated agricultural lands, and 20% of total cultivated land are affected by salinity. Additionally, the rate of salinized areas increases by 10% annually due to numerous reasons, high surface evaporation, weathering of native rocks, including low precipitation, poor cultural practices, and irrigation with saline water. By the year 2050, it has been calculated that more than 50% of the cultivated land would be salinized (Jamil et al. 2011).

Soil salinity would afflict approximately 831 million hectares of land worldwide (Martinez-Beltrán and Manzur 2005), and salinization is expected to affect 50% of all cultivated land by 2050 (Wang et al. 2003). Globally, the degree of salinization has both economic and social implications. Soil salinity not only reduces the agricultural productivity but it also hampers both the global supply of food and agricultural profits. Due to the decline in crop productivity globally, US$12 to 27.3 billion is lost annually (Qadir et al. 2014). According to the World Bank, soil salinization initiated by unsuitable irrigation exercises disturbs about 60 million ha, or 24%, of all irrigated land globally. In Africa, 50% of irrigated land is threatened due to salinization (Ceuppens and Wopereis 1999). Cumulative soil salinization is rising also in China, Central Asia, India, and Pakistan (Wichelns 1999). Practically, 35% of agricultural land undergoes salinity in Egypt (Kim and Sultan 2002, Kotb et al.

2000). The first stage of environmental destruction is soil salinization. This salinization is caused by lake and river salinization. For instance, the deviation of the Syr Darya and Amu Darya rivers not only caused momentous dehydration of the Aral Sea but also led to salinization of related agricultural land (Weinthal 2002). Soil salinization is the most critical environmental problem in Australia, initiating a dramatic change in the industry, landscape, and the future of farmland in the continent (Dehaan and Taylor 2002, Vengosh 2003). Salinity is considered a more severe problem. It occurred in Euphrates and Tigris in 4000 BC and has been a 6000-year-old problem and still affects the people of Mesopotamia.

Salinity is the most severe problem in the agricultural sector. It affects agricultural crops, and as a result, crop productivity is very low and economic development and economic growth are also low. Salinity impacts infrastructure, water supplies, the social system, and the stability of the communities. In cases of salinity, water is not given properly to plants, as needed for irrigation. That's why salt is not mixed in land. As a result, salt lives above the area of the land. Due to this, salt gathers in the zone of roots. Consequently, the land cannot work properly, and production efficiency becomes low; therefore, the land is not able to produce anything. Soil salinity is among the most important concerns globally. It turns productive land into unproductive land and also affects plant growth and agricultural production. The amount of arable land all over the world is 1.5 billion ha; because of high salinity, 77 million ha is now unfitting for crop growth. In many parts of the world, the amount of land covered by saline soil is increasing, especially those areas where temperatures and rates of evaporation are high and rain is low under arid and semiarid conditions. More than 7% of the total land on Earth is arid and semiarid. Some specific regional cases are tabulated in Table 1.1.

In different seaside districts in Bangladesh, water and soil salinity is a collective problem. Significant losses of ecosystem functions and services are as a result of soil salinity such as soil degradation, deforestation, demolition of farmhouse vegetation and loss of seaside vegetation. In the Salinity Survey Report 2010 of Bangladesh, about 2.5 million acres of cultivated land is affected by soil salinity to varying degrees, accounting for 70% of the total cultivable area (SRDI 2010). In Bangladesh, 2.5 million acres of land that is cultivated is affected by soil salinity,

Table 1.1 Global distribution of land impacted by soil salinity. (FAO 2015)

Region	Extent of salinization (million hectares)
Middle East	91.5
Asia	193.8
Africa	122.9
North America	6.2
Central and South America	71.5
Europe	6.7
Australia	17.6

which is about 70% of the total cultivable area. California has soils that naturally hold high levels of salt, like many arid and semiarid regions. Salinity has started to influence on fertile agricultural land is a very real issue for the people. In reaction to their understanding of the changes related to the salinity trend, people have been found to exploit the seasonal changeability of salinity rules in their local area. For instance, people living next to the Pasur River have occupied another strategy by gaining access to agricultural land in the Dacope sub-district, right across the Pasur, where land is appropriate for rice and winter crop cultivation. Increase in soil salinity has affected the production of rice. Rice is temperately sensitive to soil salinity. This is the case of Bangladesh, a developing country; USA is also not an exception where California has soils that naturally hold high levels of salt, like many arid and semiarid regions.

1.4 Causes of Soil Salinity

Salinity negatively affects plant growth and lessens yield. It damages infrastructure like roads, pipes, cables, and bricks. It diminishes water quality for human usage. It severely damages crops too. Salinity also causes land degradation problems. Agricultural losses due to salinity are difficult to assess, but it is estimated and expected to increase with time. Secondary agricultural land salinization is widespread in arid and semiarid environments where crop production requires irrigation schemes. Whereas the world's population continues to rise, the total land area under irrigation appears to have leveled off. There is a need for increased food production, and this can be met by increasing yield per land area. To reach this goal, genetic engineering of crops for enhanced salt tolerance will be a very important task. In dry regions where freshwater becomes a scarce commodity, irrigation of moderately salt tolerant crops is feasible. Salinity is one of the most important environmental factors limiting the productivity of agricultural crops, and there are many reasons for soil salinity, as given below.

1.4.1 Natural or Primary Salinity

Primary soil salinity is also known as naturally occurring soil salinity. It has natural causes like the accumulation of salt for a long period of time, mostly in arid and semiarid areas. It arises due to two main natural processes. Firstly, it is caused by weathering of parent rocks, through which soil is made. Weathering processes rundown rocks and discharge soluble salts of various types. These rocks contain salt such as chlorides of sodium (Na) calcium (Ca) and magnesium (Mg). They also contain sulfates and carbonates to some extent. Secondly, primary salinity is caused by the accretion of ocean salt carried by the rain and wind. In low-lying areas along the coast, soils are affected by sea water. Sea water is a source of salts. Oceanic salt or cyclic salt transferred in wind due to heat of sun (water cycle) and accumulated

Table 1.2 Magnitude of salt affected soils

Regions	Sodic soils	%	Saline soils	%	Total area
Europe	72.7	3.6	6.7	0.3	2010.8
Asia and Pacific Australia	248.6	8.0	195.1	6.3	3107.2
North America	14.5	0.8	4.6	0.2	1923.7
Africa	33.5	1.8	38.7	2.0	1899.1
Latin America	50.9	2.5	60.5	3.0	2038.6
Near East	14.1	0.8	91.5	5.1	1801.9
Total	434.3	3.4	397.1	3.1	12781.3

Adopted from Gnassemi et al. (1995)

by rainfall. Rainwater is composed of 6–50 mg/kg of salt, and as the distance from the coast increases, the intensity of salt reduces.

FAO estimated the total area of saline soil using the FAO/UNESCO soil map of the world (1970–1980). It found that there are 397 million ha salt-affected area and 434 million ha sodic soil (Table 1.2). There is almost 1500 million ha of agricultural dryland, and 32 million ha (2.1%) are salt affected. Meanwhile, there are 230 million ha of irrigated land, and 45 million ha (19.5%) are salt-affected soils, as indicated in Table 1.2.

1.4.2 Secondary/Human Tempted Salinity

Human activities such as land clearing and irrigation are also affecting a major portion of land and making the soil saline. Secondary salinity is the consequence of human actions which transform the soil's hydrologic balance between rainfall or water used for irrigation and water employed by crop transpiration. The detail of secondary soil salinity is given in (Table 1.3). There are two causes of secondary salinity. Firstly, the replacement of persistent vegetation through annual crops and land clearing caused secondary soil salinization. Secondly, the irrigation structures consuming inadequate drainage or by utilizing salt-rich irrigation water lead to secondary soil salinization. In arid or semiarid surroundings, the water utilized by natural vegetation was stable with rainfall before human's activities regarding extensive use of land. This certified that the water tables were well under the surface due to the deep roots of natural vegetation. But, this balance changed with irrigation and clearing of lands so that irrigation water and rainfall delivered extra water than the crops might utilize. This extra water raised the water table and the earlier stored salt organized in the subsoil and carried them up to the root region. Plants utilize water according to their need and depart salt until the soil water converted to saline for additional water taken up by plants. Thus, water table endures to rise and become near to surface. Salt scalds established with the evaporation of water, and leaving salt behind on the ground thus increase soil salinity.

Table 1.3 Global estimate of secondary salinization in the world's irrigated lands

Country	Area of irrigated land that is salt affected		Area irrigated		Total land area cropped (million ha)
	Million ha	%	Million ha	%	
China	6.7	15	45	46	97
India	7.0	17	42	25	169
Soviet Union	3.7	18	21	9	233
United Stated	4.2	23	18	10	190
Pakistan	4.2	26	16	78	21
Iran	1.7	30	6	39	15
Thailand	0.4	10	4	20	20
Egypt	0.9	33	3	100	3
Australia	0.2	9	2	4	47
Argentina	0.6	34	2	5	36
South Africa	0.1	9	1	9	13
Subtotal	29.6	20	159	19	843
World	45.4	20	227	15	1474

Adopted from Gnassemi et al. (1995)

1.4.3 Shortage of Freshwater

Deficiency of freshwater, including rain, rivers, and canals, is one of the chief reasons for soil salinity. For instance, insufficient rainfall is not enough to leach salts and excess sodium ions out of the rhizosphere (the narrow region of soil). Although water is abundant on the Earth's surface, and about 70% of our planet is covered by water, only 2.5% of total water is fresh. For instance, in Southern Punjab and other areas of Pakistan, where underground water is salty, out of the total land surface, almost 10% is covered by various forms of salt-affected soils while 20% of irrigated lands are affected by salinity (Jamil et al. 2011). Lands are being irrigated with tube wells and salty waters due to shortage of freshwater, and this continuous phenomenon creates salt-affected agriculture lands.

1.4.4 Salt Contamination

Through the process of osmosis, water is grabbed up by the fine roots of plants which contain the movement of water from zones of low salt intensity to zones of high salt intensity. The movement of water from the soil to the root is decelerated when salt intensity in the soil is extreme. But when the concentration of salt in the soil becomes excessive than in the inner root cells, then water will be drawn from the root to the soil; the result will be the death of plants. The production of plants is affected by this central mode of salinization. Not only osmotic forces but also toxic levels of chloride and sodium cause soil salinity. Particularly, woody ornamental plants and fruit crops are heavily effected by these elements. Moreover, excess of sodium caused by the high value of pH results in deficiencies of micronutrients.

Salt sensitivity differs in plants. Onions, lettuce, and tomatoes have lower salt acceptance, while halophytes most often occur on beaches, salt marshes, and other saline environments. Soil salinization is a common problem in low rainfall areas, and when coupled with poor drainage and irrigation, it can result in eternal soil fertility loss. Salinity in low rain fall areas is a common aspect in drought-induced humanitarian crises. Soil salinization, as a part of climatic variations, has been yet restricted entirely to tsunamis. That is why FAO is responsive and it employed several humanitarian administrations in Aceh, Indonesia. It may not have formerly confronted the phenomenon and to identify and deal with salt-affected soils due to lack of available information. Providentially, Aceh Province is bestowed with ample rainfall, which is not the case in most areas having soil salinity problems. Most areas have natural soil salinity, whereas in some areas soil salinity is caused by wind that blows nearby oceans and seas. Additionally, it has been noticed in European countries that there is upsurge in sea levels, because of which flood occurs, which in turn causes soil salinity. In most places in the world, soil salinity occurs naturally, while in some parts it is caused by the winds that blow near seas and oceans.

1.4.5 Soil Degradation

Soil degradation is another main cause of soil salinity because of the massive use of chemicals, fertilizers, and other related tools. It includes water erosion, fertility decline, wind erosion salinization, and water logging. Saline and/or sodic soil is caused by four separate conditions: (i) high salt in the parent material and low rainfall (low leaching), (ii) high rainfall with poor internal drainage, (iii) high water table that carries salt to the soil surface, and (iv) high amount of salt being applied through chemicals, manure, and poor quality irrigation water.

1.5 Impact of Soil Salinity

Generally, soil salinity affects the supply chains of agricultural products. However, their negative impact on the various ecosystems can be categorized as follows.

1.5.1 Direct Effect

In the short run, salinity impacts crops, which ultimately impact the food security and well-being of farmers because of decrease in crop production. Salt-affected areas provide less production in case of moderate soil-affected areas and sometimes no production at all in case of extreme salinity.

1.5.2 Indirect Effect

In the long run, soil salinity degrades the value of the land because of its effect on crops; hence, the long-term impact of soil salinity may result in lower land valuations on these areas. This is due to the fact that when underground water becomes saline, the lands become unsuitable for residing and agriculture purposes. This phenomenon lessens the economic value of the land.

1.5.3 Impact of Salinity on Agriculture

Agricultural crops demonstrate different reactions under salt pressure. Due to salinity, not only the production of agricultural crops declines, but the ecological balance of the area and the physicochemical properties of the soil are also affected. Low agricultural productivity, soil erosion, and low economic returns are the consequences of salinity (Hu and Schmidhalter 2002). Impacts of salinity are the consequences of composite contacts, such as physiological, morphological and biochemical procedures containing water and nutrient uptake, seed germination and plant growth (Singh and Chatrath 2001, Akbarimoghaddam et al. 2011). Salinity disturbs virtually all attributes of plant growth, including vegetative growth, germination, and reproductive development. Soil salinity executes osmotic stress, oxidative stress nutrients (N, Ca, K, P, Fe, and Zn) deficiency, and ion toxicity in plants. This results in restriction of water uptake from the soil and may cause death of plants. Soil environmental factors are the main factors that limit plant growth and the yielding of crops. Mineral toxicities, pH, temperature, structure, salinity, nutrients, water, and soil can all interact to limit plant growth. In saline soils, although pH (<8.5) and ESP (<15%) are not high, CEC is >4 mmhos/cm, and an excess of soluble salt in the subsoil restricts water uptake by crops. There are nutrient deficiencies (either roots are unable to access nutrients or there is lack of these nutrients) in the case of alkalinity. The best way to understand these limitations is to consider them in terms of the interacting factors that directly influence crop growth (OMNI ENVIRO 2018).

Soil salinity substantially lessens the phosphorus (P) uptake of plants since phosphate ions trigger Ca ions (Bano and Fatima 2009). Plants are affected by elements such as chlorine, sodium, and boron because these have distinctive noxious impact on plants. Unnecessary accretion of sodium in cell walls can swiftly lead to osmotic stress and cell death (Munns 2002). If the soil comprises plenty of the toxic components, then plants respond to essential nutrients may be influenced. Higher levels of salt in the soil can disturb the balance of nutrients in the plant or can intervene with the uptake of some nutrients because many salts are also plant nutrients (Blaylock 1994). The process of photosynthesis also affected by soil salinity via reducing leaf area, lowering chlorophyll II substance, conductance of stomatal and to some extent by decreasing photosystem II productivity (Netondo et al. 2004). Salinity disturbs generative development by dwelling stamen filament elongation and microsporogenesis, enriching death of programed cell in some tissue types, deterioration of fertilized embryos and ovule abortion.

Plant growth is adversely affected by specific ion effects (salt stress), nutritional imbalances, low osmotic potential of soil solution (osmotic stress), or a mishmash of these factors (Ashraf 2004). Altogether, these factors produce unpleasant consequences on plant development and growth at biochemical and physiological levels (Munns and James 2003) and at a molecular level (Tester and Davenport 2003). The majority of cereals and horticulture crops are glycophytes, or are sensitive to the consolidation of dissolved ions in the soil solution. Different malfunctions like ionic, secondary disorders and osmotic are created due to higher salinity at the growth and development phase of the plants (Zhu 2002). Osmotic pressure as a prime activity created by salinity usually reduces soil water potential and causes probable cell dehydration (Ondrasek et al. 2009). In plants, stomata closure arises due to osmotic pressure, so the growth of plants are disturbed. For instance, rice as a worldwide cultivated crop is also affected by salinity. Water table has direct effect on the growth of plants, and salinity raises the water table and causes accumulation of salts in the root zone. Around 45 million ha of irrigated land out of 230 million ha irrigated land is salt affected, which mean that 20% of irrigated land is salt effected. Due to high salt concentration in land, almost 1.5 million ha land is taken out of production every year and is not capable of crop production. Therefore, irrigation water also has effects on the soil. It contains calcium (Ca^{2+}), sodium (Na^{+}), and magnesium (Mg^{2+}). When water is applied to the soil after irrigation, it is mostly used by crops for production and metabolism, or it evaporates directly from the soil to the air. Calcium and magnesium ions are changed into carbonates due to chemical reactions. Sodium doesn't react and becomes dominant in the soil. However, the salt is left in the soil. As a result, the concentration of sodium is one or two times greater than the presence of macronutrients in the soil.

In relation to micronutrients, sodium is many times greater in magnitude than micronutrients. The high concentration of sodium ions in soil solution can reduce the nutrient ion activity and reacts with others ion by chemical reaction to form tremendous ratios of Na^{+}/Ca^{2+} or Na^{+}/K^{+}. The external osmotic potential rises in soil due to high concentration of cations and their salts especially NaCl. It also reduces the holding capacity of water and also decreases the invasion of water into the roots. The remaining water is in poor condition and is surrounded by a large number of sodium ions. These highly saline soils can be identified by a white layer of dry salt on the surface of the soil. There are some common and significant economic impact of salinity on a country, the industry, and the life of farmers. These are mentioned below.

1.5.3.1 Low Per-Acre Yield

Salinity causes a decline in the production of cultivated crop/acre and increases production cost. Thus, it may reduce the profitable margins of farmers.

1.5.3.2 Low Quality of Crop and Low Pricing

Land is affected by this problem known as salinity. On one side, crop production is low; on the other side, the quality of the crops is declining. These crops are low in calories and are not of fresh quality and do not meet important nutrients required for food supplies. When the quality of crops is low, they lose their competitiveness in the market. Therefore, the product is sold at a low price, which is another negative sign for farmers in terms of production. Thus, farmers' profit and income are reduced.

1.5.3.3 Decline in Productivity

When cultivable land becomes saline, it hampers productivity of land and reduces yield per acre. The production of land workers on is also reduced. So farmers' revenues also decline, which means less incentive for farmers. In developing countries, this is one of the reasons why yield per acre and yield per worker employed in agriculture are low as compared with those of developed nations.

1.5.3.4 Increase in the Cost of Production

Salinity causes the relative cost of production to increase. Per unit cost is also increased for two reasons. First, production is reduced while the cost is high. Second, to combat salinity, water pumps and chemical treatment are needed, which also bear high costs. So the overall cost of production increases, as compared to a healthy land that is free from salinity.

1.5.3.5 Low Income of Farmers

In lands where salinity is prevalent, production of crops is low, productivity is low, and yield per acre is low. Farmers cannot impose high prices on their crop products in the market because of low quality, so their revenues are low. Their profit margins are reduced because of the high cost of production and low prices because of poor quality and less revenues. The overall income of a farmer facing land salinity problems is quite low. This lowers their standard of living and their ability to buy the necessities of life.

1.5.3.6 Food Shortages

In developing countries, the problem of salinity of land is most common. They are agrarian economies, but they fail to produce crops to meet the needs of their nation. They have to import food supplies from the developed world. This is the dilemma of diseases (salinization) born on their lands due to mismanagement and lack of technology to combat salinity. Such countries always suffer from food shortages.

1.5.3.7 High Cost Involved in Combatting Salinity

When land becomes saline, crop production is reduced. Hence, it becomes necessary to combat this problem. There are many scientific and preventive solutions for this problem, but these methods involve high cost and proper, systematic management. These kinds of measures will add more to the cost of production.

1.5.3.8 Shortage of Raw Material in the Industry

Industries are agro based in most developing countries. Most of the industries buy raw materials from the agriculture sector. If agricultural production is low due to the salinity of land, there will be shortage of raw materials for the industry, and then raw materials become expensive. Thus, it creates problems for the industry as it increases the cost of production. Also, industries lose their international competitiveness.

1.5.3.9 Food Security

Most of the crops are source of crucial minerals for human beings. However, salinity may responsible for mineral shortages in billions of people due to reduction of agricultural crops productivities. Thus, salinity may cause food security in the long-run.

1.5.3.10 Dependence on Other Countries for Food Supplies and Raw Materials

Crops used in the industry as raw materials become short due to salinity. On one side there is shortage of raw materials within the industry, and on the other the price tag for the products is quite high. Thus, the industry would need to import raw materials from other countries to maintain production and supplies. They have to be dependent on other nations. Their production becomes solely dependent on the commercial policies of other countries from where they are importing raw materials. Soil salinity pastes heavy costs on the agricultural system because of reduction of yield, increase in input costs, and lower profitability and land value. The negative impact of soil salinity varies from crop to crop. For instance, some crops are more vulnerable to salinity compared with other crops.

1.5.4 Economic Impact of Soil Salinity

Salinity restricts the growth of plants and causes yield to decrease. It erodes infrastructure like cable, pipes, and bricks. The quality of water for human use diminishes, and crops are drastically affected. It also causes the problem of land degradation. There is a need to increase yield and production in order to cover the needs of the increasing population day by day. To meet this goal, this matter should be dealt with scientifically. Salinity is an environmental problem that leads to the decrease in productivity of major crops and production in agriculture in general. Salinity not only reduces the agricultural yield of most crops but also distresses the environmental equilibrium of the region and soil physicochemical characteristics. Low agricultural production, soil deterioration, and low economic revenue are the consequences of salinity (Hu and Schmidhalter 2002). Efficiency of agricultural crops is restrained due to the rigorous environmental factor that is salinity. Soil salinity is created by high consolidation of salts, and most crops are vulnerable to it. In a year, approximately $12 billion agricultural products are lost owing to salinity, and this is anticipated to rise as soils are further distressed (Gnassemi et al. 1995).

Regardless of the economic cost of production, salinity also has serious effects on water supply, the solidity of communities, infrastructure, and social structure. Plants need water and soluble minerals like salts for their optimal development and growth. So two main elements—water and soil—are necessary for cultivation. Even though most of the Earth consists of water, only a small portion (2.5%) of it is freshwater (Ondrasek et al. 2010); that is, only a small portion may be provisionally used for irrigation purposes. The rest is unsuitable for production processes. However, irrigated crops use approximately 70% of fresh water to produce approximately 36% of worldwide food (Howell 2001). In most of the agricultural regions, particularly in developing nations, water insufficiency is prominent owing to population pressure and environmental conditions. As a result, saline water is used for irrigation processes. Therefore, salt-affected land is increasing, and scarcity of food supply is becoming a bigger concern. Most of the cereals and horticultural crops, which are the source of nutrition for humans and animals, are sensitive to excessive consolidation of salts either mixed in irrigation water or existing in the rhizosphere. Salinity has created a havoc for agricultural production. For example, the recent toxic salt waste and sea disturbance in tsunami-damage region of Maldives spoiled 70% of agricultural soil, ruined 370,000 fruit trees and stirred about 15,000 farm operators, with cost predicted at around $ 6.5 million (FAO 2005). However, with the invention of new technologies in agriculture in the form of breeding and molecular biology, it is suggested that salt acceptance in plants is one of the most effective approaches for food production in the existence of salinity.

Na^+ and Cl^- are two of the most significant ions that stimulate salt pressure in plants. Sodium is not an important but a beneficial component, whereas chlorine is a necessary nutrient (Marschner 1995). However, both elements are deadly if these are in too much concentration form, generating particular disorders and creating considerable damages crops. The impact of soil salinity varies from crop to crop and region to region and even varies with regard to the same crop existing in different regions. As there is no generality regarding the impact of salinity on crops, we presented some case studies for different crops in different regions, although mostly salinity impacts the crops negatively.

According to a pioneering study on the issue, in South Asian countries like Pakistan, Iran, India, Bangladesh, Sri Lanka, Afghanistan, Bhutan, and Nepal, the costs of land degradation are at least US$ 10 billion annually. It is almost 2% of GDP in the region, which is equal to 7% of its agricultural value of output (Shah and Arshad 2012).

Shah and Ashraf (2012) found the economic losses due salinization according to the categories of land degradation such as losses due to fertility decline US$ 1.5 billion; water erosion US$ 0.5 billion; and wind erosion US$ 1.8 billion. Further, they found that overall 140 million ha (e.g., 43% of the area's total agricultural land) is affected due to land degradations such as salinization. Out of this, moderately degraded land is 63 million ha, while 31 million ha of land was strongly degraded. The country affected the worst was Iran, with 94% of its agricultural land degraded, followed by Bangladesh (75%), Pakistan (61%), Sri Lanka (44%), Afghanistan (33%), Nepal (26%), India (25%), and Bhutan (10%). Ripplinger et al. (2016) found that on moderately saline soil (5 mmhos/cm), wheat yields are 80%, soybean yields are 16%, and corn yields are 65% of the relative yield. It means that soybean is highly sensitive to increasing salinity. On the revenue side, they found that the expected wheat revenues fall from $214 to $278 per acre, soybean revenues fall from $276 to $50 per acre, and corn revenues fall from $472 to $305 per acre when soil salinity is 5mmhos/cm. On the other hand, Naifer et al. (2011) found that salinity caused havoc to agriculture of Oman. For instance, they estimated that as the soil salinity increases from low to moderate, the damage goes from US 1604ha^{-1} to US2748 ha^{-1}.