1 Soil Salinity and Sodicity as Particular Plant/Crop Stress Factors

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CONTENTS

1.1 INTRODUCTION

Soil salinity and sodicity are among the major agricultural problems limiting plant growth and development throughout the world [2,6–8,10,12–18,22,23,26,29,30,32–35,40,42,48–52,54,59–63, 66,67,71–74,80,83–86,100,105–107,109,110,112,114,115,121–124,132–134,136–144,149–152]. Salinity and sodicity problems in agriculture have an ancient history, and presently have become a very cumbersome problem in agricultural and farming activities [153]. These problems are especially of great concern for countries that their economies rely to a great extent on agriculture.

Salinity and sodicity problems are common in arid and semiarid regions, where rainfall is insufficient to leach salts and excess sodium ions out of the rhizosphere. In addition, these areas often have high evaporation rates, which can encourage increase in salt concentration at the soil surface. The arid and semiarid regions include almost one-third of the world's land [80,108,114]. According to the Food and Agricultural Organization (FAO) [46] of the United Nations, total salt-affected area of the world has been estimated to be over 800 million ha.

The presence of a cliche horizon and/or a cemented hardpan layer at varying depths plus insufficient precipitation for leaching often adds to the salt accumulation in these soils.

Newly established irrigation projects, with improper planning and management practices, may also add salts to soils [88].

Soil salinity and sodicity problems are present in nearly every irrigated area of the world and also occur on nonirrigated croplands and rangelands. Thus, virtually no land is immune to salinization. Therefore, for sustaining life on earth, control of these problems and finding new ways to utilize these extensive saline and sodic soils and water resources, at least for agricultural purposes, are vital and urgent. Reclamation, or at least minimizing the effect of salinity and/or sodicity, is important

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and necessary. In this respect, proper utilization of water for both plant growth and soil salinity and sodicity control is probably of the greatest importance.

The main focus of this introductory chapter is to summarize general information on salt-affected (saline and sodic) soils, factors influencing their formation and reclamation, and discussing salinity and sodicity as plant/crop stress factors.

1.2 SIGNIFICANCE OF SOILS IN RESPECT OF CROP STRESS

As far as all the crops are grown on soils, soil properties have substantial influence on the life conditions of plants and crops. In nature, usually particular plant species grow on specific soils. Thus, specific relationships exist between a particular soil and the vegetation cover of that specific soil. For example, Kreeb et al. [68] investigated soil and vegetation relationships associated with sodic–saline soil surfaces.

Plant development and successful crop production require proper soil conditions, including adequate water and nutrient supply. Unfavorable soil conditions, environmental stress [2,31,130,135], salinity and/or sodicity [6–8,13,14,18,22,25,26,29,34,40,51,54,60,62,66,71,83,85,91–94, 96,97,115,124,132,133,136,137,139–142,148,149,151], and inadequate nutrient supply [98,145] have an adverse effect on the life of the plants, sometimes seriously hindering their effective production.

Based on the above facts, we can speak of stress factors originating in the soil, i.e., such unfavorable soil conditions which cause, or contribute to, the stress factors plants and crops are exposed to.

It is impossible to list all or most of such factors in a short introductory chapter. Therefore, the authors limit the range of this chapter to a general description of soil behavior and its function in nature and production as well as to an outline of one of the most serious factors originating salt-affected soils. For more in-depth information regarding salt-affected soils, the readers are referred to more comprehensive available sources [9,21,24,27,37,41,43,69,77–79,82,87,97,106,113,119,125,128,129,146,147].

1.3 PLACE AND ROLE OF THE SOIL IN NATURE

It is generally accepted that the soil is a substantial part of the environment, comprising different substances and forming a special kind of ecosystem inside the given ecosystem, with various properties and attributes. It is also accepted that the soil of the continents is of high diversity, which is dealt with by several branches of soil science, e.g., taxonomy, classification, survey, mapping, etc.

The soil, or the pedosphere, which is an environmental synonym of the soils of a given territory, has a specific place in nature. It is a natural body, similar to rocks, waters, or biota, in the sense that they too have their own materials, mass and energy fluxes, development, and regularities. This fact should be mentioned because, not only in newspapers but also in technical literature, soils are frequently treated either as living substances or as nonbiological substances. Neither of these approaches is correct, because one of the characteristics of the soil is its complexity, the fact that it contains both living and nonliving substances, forming due to both biotic and abiotic processes.

The soil as a natural body is inseparable from the rocks and the crust of weathering on the surface of the continents from which it has developed, on the one hand, and from the biological processes on the other hand. The main characteristics that distinguish the soil from the rocks is the result of biological processes: the production of organic matters by the activities of microorganisms, plants, invertebrates, and other animals, and, finally, human beings, which transforms the rocks into soils, capable of supplying plants and crops with nutrients and water, and being an anchor for their establishment and stands on the land.

The processes of soil formation started concurrently with the appearance of life on the continents and continued during the billions of years of interactions between living substances and rocks under the influence of climatic conditions, with particular regard to the action of water, vegetation cover, organism (both macro and micro), geomorphological patterns, and the time factor. As a result of their interactions, specific mass and energy fluxes formed the different soil types in various environmental conditions.

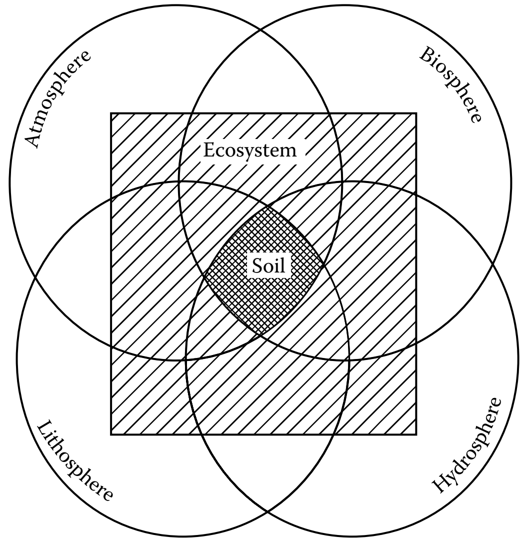

FIGURE 1.1 Schematic diagram of the interaction of lithosphere, atmosphere, biosphere, hydrosphere, ecosystems, and soils. (From Szabolcs, I., *Salt-Affected Soils*, CRC Press, Boca Raton, FL, 1989.)

With the appearance of the human race on the face of the earth, even changes in the environment became different. Due to human activities, the natural processes affected by biotic and abiotic factors accelerated, and several others that were unknown or minimal before developed.

The role of soils in nature is complex and multisided, including biospheric, hydrospheric, and lithospheric functions. Their interaction is illustrated in Figure 1.1 [128]. Figure 1.1 clearly shows that the soil is a specific body related to the ecosystem. Even the word "soil" is very often used as a synonym of ecosystem when characterizing the given ecological conditions in a certain place. If we want to be precise, we must agree that the ecosystem includes the pedon, in other words, the soils. However, the soil includes different phases (solid, liquid, gaseous), living and nonliving substances, plants, animals, microbes, and has its own energy and material fluxes. Therefore, it can be considered an ecosystem in itself. In this respect, when speaking of soils versus their plant cover, we can consider the soils of a given location as the basis, ladder, and foothold, for instance, that in savannas or in the tropical belt, a well-defined plant cover develops and very often the soil properties promote or limit the living conditions of certain plant species or associations.

Based upon the above considerations, it can be accepted that certain soil types, when discussed as the habitat for certain plant associations, are often named as the ecosystem of the plant association concerned, as the pedon includes, apart from the plants, most of the components of the ecosystem.

Evidently, the soil, as a specific natural entity, is far from being identical with the vegetation, and, in spite of their close correlation, direct conversion between soil types and vegetation is hardly possible. Still there are soil types that, more or less, determine the ecological function for certain types of vegetation either by providing beneficial conditions for their development or by limiting the ecological conditions for other types of vegetation.

This is perhaps best demonstrated in the case of salt-affected soils where high electrolyte contents of extreme pH conditions limit the development of the majority of plants and serve as a habitat only for such species that can survive or tolerate the unfavorable conditions caused by the salinity and sodicity of the soil. For example, the grass *Leptochloa fusca* that grows vigorously on the salt-affected soils can tolerate extremely saline and sodic (alkaline) conditions [69]. This species is also well adapted to the waterlogging encountered on saline and sodic (alkaline) soils. Saltgrass (*Distichlis spicata*) is another example of a highly salt-tolerant plant species that grows vigorously on saline and sodic soils [76,89–92,94–96]. In fact, the intensive investigations of the senior author of this chapter and his coworkers on this plant species have found that this grass performed better than control when some salt was added to it during its establishment period, and so far it has been the most salt- and drought-tolerant species compared to the other highly salt-tolerant halophytes that have been tested by this investigator [89,90,94]. Other investigators [39,68,97,111] have also reported on the soil and vegetation relationships that specific plant types are adapted and growing on specific habitats. In such respects, salt-affected soils can be considered as habitat or ecosystems for halophytes, and, if we agree on this, correlations can be found between the different types of salt-affected soils and their flora and fauna as components of the ecosystem.

In order to cast light on both the theoretical and practical aspects of such considerations, it is necessary to describe briefly the properties and grouping of salt-affected soils with regard to the possibilities of the occurrence and distribution of halophytes and xerophytes developing on them.

1.4 EXTENSION AND GLOBAL DISTRIBUTION OF SALT-AFFECTED SOILS

Nearly 10% of the total land surface is covered with different types of salt-affected soils. Table 1.1 demonstrates the distribution of salt-affected soils in the world [65]. Table 1.1 shows that no continent on our globe is free from salt-affected soils. They are distributed not only in deserts and semidesert

TABLE 1.1
Salt-Affected Soils on the Continents and Subcontinents

Continent	Area (Millions ha)
North America	15.7
Mexico and Central America	2.0
South America	129.2
Africa	80.5
South Asia	87.6
North and Central Asia	211.7
South-East Asia	20.0
Australasia	357.3
Europe	50.8
Total	954.8

FIGURE 1.2 Global distribution of the salt-affected soils.

regions, but also frequently occur in fertile alluvial plains, river valleys, and coastal areas, close to densely populated areas and irrigation systems [27,37,41,45,46,78,87,108,112,128,129].

Figure 1.2 shows the distribution of salt-affected soils throughout the world [129].

1.5 DEVELOPMENT AND GROUPING OF SALT-AFFECTED SOILS, PARTICULAR PLANT/CROP GROWTH STRESS FACTORS

In spite of the fact that the properties and attributes of salt-affected soils have been well known for a long time, it is appropriate to give a brief definition of this group of soils right at the start, because the salinity and sodicity (alkalinity) as well as the acidity of soils are substantial stress factors, seriously affecting the productivity of the land [2,7,8,10,12–18,22,23,25,26, 28–33,35,36,40,42, 48–52,54,56,59–63,67,70–74,80,83–87,98–100,105–107,109,110,112,114,115,121–124, 128–130,132–133,143–145,148–150,153].

Salt-affected (i.e., saline, saline–sodic, and sodic) soils usually have low biological activity both because of osmotic and ionic effects of salts and due to limitation of carbonaceous substrates. Rao and Pathak [103] reported that microbial growth was depressed in sodic (alkali) soils due to, at least in part, limitation in carbon substrate (carbon stress), and in saline soils due to salt stress.

For detailed information on the formation of salt-affected soils, the readers are referred to Szabolcs [128,129] and Pessarakli [87].

Salt-affected soils can be characterized as soils formed under the dominant influence of different salts in their solid or liquid phases, which will then have a decisive influence on the development, characteristics, physical, chemical, and biological properties, and eventually the fertility of the soil. Whenever and wherever this phenomenon occurs, it produces specific formations of soils where the high electrolyte concentration and its consequences overshadow the former soil-forming processes or former soil properties and environmental conditions, often radically changing them.

High electrolyte concentration is the only common feature of all salt-affected soils. Their chemistry, morphology, pH, and many other properties may be different, depending on the character of salinization and/or alkalization.

Salt-affected soils, in the broader sense, can be divided into the following groups:

1. Saline soils that develop under the influence of electrolytes of sodium salts with nearly neutral reaction [dominantly sodium sulfate (Na_2SO_4), sodium chloride (NaCl), and seldom sodium nitrate ($NaNO_3$)]. These soils occur mainly in arid and semiarid regions and form a major part of all the salt-affected soils of the world.

   High contents of soluble salts accumulated in these soils can significantly decrease their value and productivity.
2. Sodic (alkali) soils that develop under the influence of electrolytes capable of alkaline hydrolysis [mainly sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$) and seldom sodium silicate (Na_2SiO_3) and sodium bisilicate ($NaHSiO_3$)]. This group is well extended in practically all the climatic regions from the humid tropics to beyond the polar circles, and their total salt content is usually lower than that of saline soils, sometimes even strongly sodic (alkaline).

   Virgin sodic (alkali) soils have a high pH and high exchangeable sodium (Na) percentage (ESP) and are often barren.

   Sodic soils exhibit poor physical conditions that adversely influence water and air movement in the soils. Sodicity causes soil erodibility and impairs plant growth [82,87].
3. Salt-affected soils that mostly develop owing to the presence of calcium sulfate ($CaSO_4$) [gypsiferous soils] or, rarely, in the presence of calcium chloride ($CaCl_2$). Gypsiferous soils can mainly be found in the arid and semiarid regions of North America, North Africa, the Near East, Middle East, and Far East, and also in Australia.

4. Salt-affected soils that develop under the influence of magnesium salts. This group occurs in arid, semiarid, and even semi-humid regions, and has a particular significance, especially those soils that have a heavy texture.
5. Acid-sulfate soils whose salt content is composed mainly of $Al_2(SO_4)_3$ and $Fe_2(SO_4)_3$. This type of salt-affected soils is broadly extended in the tidal marsh areas along the seashores of all the continents. These soils are particularly common in North Europe, the western and eastern coastlines of Africa, along the coastline of South-East India, and develop on sulfurous marine sediments.

Inland acid-sulfate soils can also be found in different areas of the world, such as the western territories of the United States, Asia Minor, and China. Such soils develop as a result of fluvial glacial processes and have had no connection with seashores in recent geological times.

Evidently, the different groups of salt-affected soils have diverse physicochemical and biological properties besides the one they have in common, i.e., a comparatively high electrolyte content.

The grouping of the salt-affected soils and their properties causing plant and crop stress are presented in Table 1.2.

The five groups in Table 1.2 represent the formations of different salt-affected soils described above, indicating their chemical types, the environmental conditions where they dominate or occur, the pattern of their main adverse effect on production, and the basic methods of their reclamation. For detailed information on formation and reclamation of salt-affected soils, see Szabolcs [128,129] and Pessarakli [87].

In Table 1.2, the adverse properties of different salt-affected soils causing crop stress are also included. From these, it is clear that, in various groups, different properties are responsible for hindering the development of plants and crops by causing stress.

In saline soils, it is the high salt concentration in the solid and liquid phases that results in high osmotic pressure, hindering the normal development of plants, the stress factor is the salinity with

TABLE 1.2
Grouping of Salt-Affected Soils and Their Properties Causing Plant and Crop Stress

Types of Salt-Affected Soils	Electrolyte(s) Causing Salinity and/or Sodicity	Environment	Properties Causing Plant and Crop Stress	Methods for Reclamation
Saline	Sodium chloride and sulfate (in extreme cases nitrate)	Arid and semiarid	High osmotic pressure of soil solution, toxic effect of chlorides	Removal of excess salt (leaching)
Sodic	Sodium ions capable of alkaline hydrolysis	Semiarid, semi-humid, and humid	High (alkali) pH, poor water physical conditions	Lowering of neutralizing the high pH by chemical amendments
Magnesium	Magnesium ions	Semiarid and semi-humid	Toxic effect, high osmotic pressure, Ca deficiency	Chemical amendments, leaching
Gypsiferous	Calcium ions (mainly $CaSO_4$)	Semiarid and arid	Low (acidic) pH toxic effect	Alkaline amendments
Acid sulfate	Ferric and aluminum ions (mainly sulfates)	Seashores and lagoons with heavy, sulfate-containing sediments, diluvial inland slopes and depressions	High acidity and the toxic effect of aluminum	Liming

all its disadvantageous consequences of plant life. Apart from this, some compounds of the salt content of these soils, e.g., chlorides as toxic elements, also act as one of the stress factors.

In sodic (alkali) soils, as a rule, not the high salt concentration but the sodic (alkaline) pH value is the stress factor, particularly in cases where there is a high concentration of sodium carbonate in the solid and liquid phases of the soil. The high pH hinders the life function of crops and limits their development.

In another group of sodic (alkali) soils, which sometimes does not have very alkaline pH value (solonetz type), the comparatively low concentration of sodium salts capable of sodic (alkaline) hydrolysis constitutes a stress factor through its action, resulting in poor water physical properties in the soil. As a consequence of this phenomenon, the wilting point in the soil increases and the plants suffer from water deficiency, even in wet soils, due to the swelling of clay saturated with sodium ions (Na^+).

In magnesium soils, which have not been adequately studied, the combination of toxic effect, calcium deficiency, and poor soil physical properties are the stress factors.

In gypsiferous soils, the acidic pH and sometimes the toxic effect of the high gypsum content, contribute to the appearance of stress factors for plant and crop life in areas with large extensions of intensively gypsiferous soils.

In acid-sulfate soils, the very high acidity, with a pH sometimes below 2, poses stress with all the adverse effects of extreme acidity. Furthermore, the high aluminum content of the soil solution has an intensive toxic effect.

Apart from this, the temporary or permanent waterlogging in such soils acts as a stress factor, hindering the normal air and nutrient regime, necessary for plant life, in these soils.

Besides the salt-affected soils developing due to natural soil-forming processes, the so-called secondary salt-affected soils have an increasing importance that is both scientific and practical. Secondary salt-affected soils are those that have been salinized due to man-made factors, mainly as a consequence of improper methods of irrigation. The extension of secondary salt-affected soils is rather sizeable, and this adverse process is as old as irrigated agriculture itself. Old civilization in Mesopotamia, China, and Pre-Columbian America fell in consequence of the salinization of irrigated land. The process is also advancing vigorously at present and more than half of all the irrigated lands in the world are under the influence of secondary salinization and/or alkalization.

When speaking of the man-made factors of salinization, we also have to mention potential salt-affected soils that are not salt-affected at present, but in case of the extension of irrigation, deforestation, overgrazing, and other man-made measures, can and will be salinized unless the necessary preventive procedures are undertaken in due time. No global records are available of the size of potential salt-affected soils; however, the area that they cover is larger than that of existing salt-affected soils.

Secondary salt-affected soils can be divided into the following two categories:

1. Secondary formation of salt-affected soils caused by irrigation.
   In spite of the negative experiences, the salinization of irrigated and surrounding areas has not diminished. On the contrary, it is still on the increase.

   According to the estimates of the FAO and UNESCO (the United Nations' Educational, Scientific and Cultural Organization), as much as half of all the existing irrigation systems of the world are, more or less, under the influence of secondary salinization, alkalization, and waterlogging. This phenomenon is very common not only in old irrigation systems but also in areas where irrigation has only recently begun.

   According to the estimates of the above mentioned agencies, 10 million ha of irrigated land are abandoned yearly because of the adverse effects of salinity due to irrigation, mainly secondary salinization and alkalinization.

   The mentioned losses and damages are not evenly distributed among the irrigating countries. In some of them, the damage may be relatively small, while in others it actually constitutes the major problem in agriculture or even in the national economy of the country in question. In this respect, unfortunately, there are countless sad examples.

In Pakistan, Ahmad [4] carried out statistical analyses in respect of secondary salinized land. According to his data, out of 35 million ac (approximately 16 million ha) of total irrigated territory, salinized areas account for 5.3 million ac (approximately 2.4 million ha) after a few years of irrigation. He indicated among the causes of secondary salinization in Pakistan the joint effect of irrigation and ground water. According to Zavaleta [147], practically all irrigated alluvial soils in Peru show the features of salinity and sodicity (alkalinity). It is known from FAO reports [45,46] and the papers of Kovda [64] that more than 40% of irrigated soils in Iraq and Iran are affected by secondary salinization. A country report by FAO [45] on salinity in Syria estimated the adverse effects of salinity as follows:

a. In more than 20,000 ha, salinity developed to a level where these soils had to be taken out of cultivation, and the loss is estimated at a total of 30,000 ton of cotton per year.
b. In about 30,000 ha, the yield decreased by 50% and the total loss is estimated at 20,000 ton of cotton per year.
c. In about 60,000 ha, the yield decreased by 20%, and the total loss is estimated at about 18,000 ton of cotton per year.

At present, no continent is free from the occurrence of this very serious phenomenon. In Argentina, 50% of the 40,000 ha of land irrigated in the nineteenth century are now salinized. In Australia, secondary salinization and alkalization take place in the valley of the river Murray, and in Northern Victoria 80,000 ha have been affected. The same phenomena can be observed in Alberta, Canada, and similar processes have been recorded in the northern states of the United States, where irrigation was introduced much later than in the dry west. It is noteworthy that these last examples, and many other irrigated regions, are far from being arid areas and the majority of salt accumulations are associated with the sodium salts capable of sodic (alkaline) hydrolysis, and not with the neutral sodium salts that we are familiar with in desert and semidesert areas.

The more recent reports of the FAO [46] of the United Nations estimated the salt-affected areas due to irrigation in the developing countries, including the above mentioned ones (Iran, Iraq, Pakistan, and Syria) much higher than the previous reports.

2. Secondary formation of salt-affected soils caused by human activities other than irrigation. When speaking of secondary salinization, most people think of irrigation and drainage. However, there are also other anthropogenic factors causing this adverse phenomenon. It is true that the majority of secondary salt-affected soils develop as a result of improper methods of irrigation, but there are other human effects that more and more often trigger this process in many places, both in arid and humid areas.

Some of these anthropogenic processes are, including but not limited to, the following:

a. Overgrazing

This process occurs mainly in arid and semiarid regions, where the natural soil cover is poor and scarcely satisfies the fodder requirement of rather extensive animal husbandry. If, due to overgrazing, the natural vegetation is sparse or annihilated, progressive salinization develops and, step by step, the scarcity of the plant cover becomes increasingly pronounced. Sometimes, the process ends in desertification because even the poor pasture diminishes and no other fodder resources are available. According to Theunissen [131], the gradual decline in the ecological condition of natural pastures as a result of overgrazing and the application of insufficient management decisions, coupled with the detrimental effects of long-term drought, has left extensive areas of high potential grazing land in southern Africa in urgent need of restoration. However, due to the limited number of grasses currently available for rehabilitating and restoring the vast number of different habitats encountered, selecting indigenous grasses suitable for restoration of denuded areas in the arid and semiarid grasslands of Southern Africa was initiated.

b. Deforestation in semi-humid and semiarid areas
Particularly, in the last few decades, it has became evident that deforestation results in many tropical and subtropical countries in the salinization and alkalization of soils due to the effects of soil migration both in the upper and the lower layers. In South East India, e.g., vast territories of former forest land became intensely saline and sodic (alkaline) in a few years after the annihilation of the woods. Similar phenomena occurred in the forest steppe areas in Russia, Iran, East-Central Europe, and Latin America.

c. Salinization caused by contamination with chemicals
In spite of the fact that the amount of chemicals applied in agriculture is practically negligible, in comparison to the salt content of several soils, we have considered the fact that this kind of salinization more and more often occurs in modern intensive agricultural production, particularly in greenhouses and intensive farming systems. When production takes place in semi-closed systems (e.g., greenhouses), where the chemicals applied will not be removed regularly, the accumulation of salts or their components becomes possible in the upper layer of the soil, resulting in salinity and sodicity (alkalinity). In Japan, the Netherlands, and other countries with intensive agriculture, and particularly horticulture, such type of salinization more and more frequently appears, causing serious losses of crop yields.

d. The accumulation of airborne or waterborne salts
Due to the concentration of industrial plants, the emission of chemical compounds may accumulate in the soil and, if their concentration is high enough, they result in salt accumulation in the upper layer of the soil.

A similar phenomenon appears when, due to water system regulations, sludge water disposal, and other hydrotechnical measures, water with considerable salt concentration contaminates the upper soil layer, causing salinization and/or alkalization.

1.6 RECLAMATION OF SALT-AFFECTED SOILS, RELIEVE OR ELIMINATION OF PARTICULAR PLANT/CROP STRESS FACTORS

The major environmental stresses caused by soil salinity and sodicity have existed long before the agricultural practices have started. Soil salinity and sodicity have a substantial effect in reducing agricultural production worldwide [2,6–8,10,12–20,22,23,26,29,30,32–35,40,42,48–52,54,59–63,66,67,71–73,80,83–86,100,105,107,109,110,112,114,115,121–124,132–134,136–144,148–150,152]. This has a major impact on increased food and feed insecurity globally, particularly in developing countries that are more prone and vulnerable to salinization and desertification due to lack of advanced technology, adequate education, and other socioeconomical and technological problems. Population growth and increasing demand for food and agricultural products necessitate using the salt-affected soils and marginal lands for food production. These soils are needed for the agricultural extension and, hence, reclamation is required. Reclamation is needed on the millions of hectares of slowly permeable salt-affected (i.e., saline–sodic and sodic) soils throughout the world [2,46,55,63,87,112,124,150].

Different techniques of reclamation and preventive measures or management practices are used for reclamation of salt-affected soils and reducing the salt contents of the growth medium or to find more stress-tolerant plant/crop species and cultivars via genetic engineering to combat salinity stress. These management practices were aimed to enable plants to grow in saline and sodic conditions to utilize salt-affected soils for agricultural practices and food production [2,3,5,10,12,15–20,23,28,30,32,33,35,38,42,44,47–49,52,56,59,61,63,69,72,80,81,84,86,87,99,100,105,107–110,114,117–119,121–124,126,131,134,138,143,144,149,150,152]. Saline soils are usually reclaimed by leaching the salts out of the soil through irrigation and drainage systems, whereas reclamation of sodic (alkaline) soils requires application of chemical amendments followed by the leaching process.

Present recommendations for reclamation of the salt-affected soils are usually based only on relatively simple and often empirical relations. Various amendments and management strategies have been used for reclamation of the salt-affected soils. To evaluate particular reclamation strategies, some specific considerations should be noted as follows:

1. The quantity of water needed
2. The quality of water needed
3. The quantity of amendments to be used
4. The type(s) of amendment(s) to be used
5. The time required for reclamation to be completed

Chemical reactions such as cation exchange, precipitation, and dissolution of solid phases (reclamation amendments) and the soil hydraulic properties and corresponding changes in the water flow and solute transport rates must be considered [119].

Among the various reclamation practices, usually, a combination of added gypsum amendment and crop rotation has been proven the best.

Reclamations of salt-affected (saline–sodic and sodic) soils by chemical amendments has become cost-intensive and requires high capital investment, and are not always a practical solution to the problem of soil salinity and sodicity. Therefore, biotic approach such as cultivation of salinity- and sodicity-tolerant plants and crops on salt-affected soils, i.e., "saline agriculture," may be another alternative.

Cultivation of different salinity- and sodicity-tolerant plant types and species have been used by several investigators, i.e., grasses [44,62,69,75,76,89–91,93–97,99,131,140,148], agronomic crops [5,15,16,19,20,23,42,47,48,61,63,72,73,81,86,108,114,121–123,149,150], forest species, and trees [10,28,54,117,118,126] for reclamation purposes. These plants can mobilize the native lime (calcium carbonate, $CaCO_3$) in these soils through root action, a substitute for the chemical approach. Qadir et al. [97], studying the combination of chemical amendments and biological (using plants) reclamation technique, reported that the soil treated with gypsum at a high rate (100% GR, grade reagent) removed the greatest amount of Na^+ from the soil columns and resulted in a marked decrease in soil salinity (EC, electrical conductivity) and sodicity, sodium absorption ratio (SAR), and ESP (exchange sodium percentage). The performance of grass treatment in enhancing the leaching of Na^+ was between the gypsum treatments.

According to Kumar [69] and Qadir [97], the grass, *Leptochloa fusca*, was very useful and effective in the reclamation of salt-affected soils. This plant can tolerate extremely saline and sodic (alkaline) conditions. Since its growth is not affected by gypsum application, planting with *Leptochloa* is an alternative biological rather than a chemical method for the reclamation of sodic (alkaline) soils. This plant is also well adapted to the waterlogging encountered on saline and sodic (alkaline) soils. The plant improves the soil's physical, chemical, and biological properties so that within 2 or 3 years many commercial and forage crops can be grown on the soil [69]. *Leptochloa* excretes salts through specialized glands and is, therefore, reasonably palatable to farm animals. It must be noted that because of its vigorous growth on sodic (alkaline) soils, *Leptochloa* does not allow satisfactory growth of companion plant species, especially in the initial years of soil reclamation.

Subramaniam and Babu [126] also used a forest shrub species for reclamation of sodic soils. According to these investigators [126], *Sophora mollis*, which is a shrub to medium-sized tree and is used for both fodder and firewood, can be used in the reclamation of sodic (alkaline) soils.

Kilic et al. [63] investigated the salt-removing capacity of purslane (*Portulaca oleracea* L.) by studying different stress criteria and by tracking its salt removal from germination to harvest. The results of their study showed that purslane could cumulatively remove considerable amounts of salt from the soil if practical to cultivate as an intercrop all year round.

Saltgrass (*Distichlis spicata*) that has been found the only vegetation cover on a highly sodic (alkaline) soil in Wilcox Playa, Arizona [92] can also be very effective in reclamation of saline and sodic soils. As mentioned earlier, the senior author of this chapter and his coworkers found this grass to be very high salt-tolerant plant species that grows vigorously on saline and sodic soils [76,89–92,94–96]. Compared to the other highly salt-tolerant halophytes that have been tested by this investigator [89,90,94], so far, this grass has proven the most salt and drought tolerant of all the tested species.

Although slow, definite improvement is achieved in the physicochemical properties of the salt-affected soils by encouraging the vegetation growth on such lands. The tree species in general are effective in improving the soil properties as reflected by the changes in physicochemical characteristics of the soil such as bulk density (BD), water holding capacity (WHC), hydraulic conductivity (HC) and pH, EC, OC (organic carbon), N (nitrogen) and exchangeable cations (Na^+ and Ca^{++}) [117].

Due to the low biological activity and depressed microbial growth of salt-affected (i.e., saline, saline–sodic, and sodic) soils, there is a need for applying organic amendments (i.e., plant residue or manure) during sodic (alkali) soil reclamation. In reclamation of saline soils, organic amendments must be applied following the leaching process.

Kumar et al. [70] conducted a combination of biological and chemical reclamation study on a highly sodic (alkaline) soil. These investigators [70] found that rice produced satisfactory yields in the first year of gypsum application, but sorghum and *Sesbania* yields were very poor. The yield of *Leptochloa* was not affected by gypsum application. In their crop rotation practice, Kumar et al. [70] reported that the green forage yield of sorghum was greatest when sorghum followed *Leptochloa* grown for 2 years and the harvested grass was left to be decomposed on the site.

In a biological reclamation study of saline soils, Helalia et al. [53] reported that amshot grass significantly reduced the soil salinity compared to either ponding or gypsum application, and this grass produced a higher fresh yield than clover cultivated in such soils.

The above findings indicate that biological reclamation with the salinity- or sodicity-tolerant plants (i.e., *Leptochloa*, grasses, shrubs, or trees) is a proper substitute for chemical reclamation with gypsum, and the former has an economic advantage over the latter.

Yildirim et al. [144] evaluated the effects of selected biological treatment on direct seeded and transplanted squash plant growth and mineral contents under salinity stress. These investigators reported that salinity negatively affected growth of squash; however, biological treatments significantly increased fresh weight compared to nontreated plants that were under salt stress. They also found biological treatments increased the uptake of potassium compared to the nontreated control in both direct seeded and transplanted squash. Based on their results, these investigators concluded that alteration of mineral uptake may be one mechanism for the alleviation of salt stress, and the use of biological treatments may provide a means of facilitating plant growth under salt stress conditions.

Compost or any other organic materials is recommended to be used during the reclamation process of the salt-affected soils. The results of a field experiment conducted by Avnimelech et al. [21] verified that compost application improved both physical and chemical conditions of saline and sodic (alkaline) soils. Compost application to such soils is expected to release acids, which would ultimately lead to the replacement of exchangeable sodium by calcium. In addition, compost application would stabilize soil structure and enhance plant growth. These investigators [21] found that the municipal solid waste compost application was equivalent or even superior to the addition of gypsum, the most common amendment used to reclaim sodic (alkaline) soils. This was evident from the substantial increase in crop yields. The combined application of compost and gypsum raised yields to the levels equal to that of the commercial fields.

In a field experiment, Batra et al. [24] compared the microbiological and chemical amelioration of a highly deteriorated sodic (alkaline) soil using two reclamation technologies:

1. Growing Karnal grass (*Leptochloa fusca*) as a first crop with no chemical amendment (biological reclamation)
2. Gypsum application as a chemical amendment for different crop rotations

These investigators [24] reported that the microbiological properties changed more than the chemical properties of sodic (alkali) soil as the time period advanced.

In a biological reclamation study carried out on saline soils, Apte and Thomas [11] found that a brackish water, nitrogen-fixing cyanobacterium, *Anabaena torulosa*, could successfully grow and fix nitrogen on moderately saline soils (EC of 5–8.5 dS m^{-1}). These investigators [11] reported that cyanobacterium exhibited high rates of nitrogen fixation and substantially enriched the nitrogen status of saline soils. However, permanent removal of Na^+ from saline soils using cyanobacteria or any other microorganisms may not be possible, since Na^+ is released back into the soil subsequent to the death and decay of cyanobacteria or other microorganisms. Amelioration of soil salinity by simultaneous application of *Anabaena torulosa* during crop growth seems to be an attractive possibility for reclamation, especially since it can also supplement the nitrogen requirement of the crops growing on these soils.

Blue-green algae that tolerate excess Na and grow extensively on the soil surface in wet seasons were found effective in sodic soils reclamation [102]. However, a permanent reclamation of such soils by using only blue-green algae as a biological amendment to achieve sodic (alkali) soil reclamation is neither possible nor comparable with an effective chemical amendment such as gypsum.

In the reclamation process of the saline soils, de Villiers et al. [39] compared different annual and perennial species. Of the six species tested, the perennials seemed to be more effective and better suited for rehabilitation purposes under saline soil conditions.

The type of chemical compound being used also influences the reclamation process of salt-affected soils. Sharma and Upadhyay [116] reported that, among the up-to-date known chemical compounds, cyclohexathiazenium chloride (S-6N-4)-2+Cl-2 is the best and the most suitable chemical to reclaim the sodic (alkaline) soil at any pH of the soil.

When good quality water is not available for leaching the salts out of the soil, low-quality water can be used for the initial stages of reclamation. In this regard, Singh and Bajwa [120] studied the effects of gypsum and sodic irrigation on the precipitations of Ca^{++} and removal of Na^+ from a sodic soil reclaimed with different levels of gypsum and growth of rice in a greenhouse experiment. Dubey and Mondal [43] also used low-quality saline water in conjunction with organic and inorganic amendments for initial stages of reclamation of sodic soils. Using low-quality water, Joshi and Dhir [58] evaluated the rehabilitation of degraded sodic soils using residual sodium carbonate water (low-quality water) combined with gypsum treatment and found that the combination treatment was effective in lowering the soil SAR (sodium absorption ratio) and improved water infiltration rate. In the first year of gypsum treatment, it was possible to establish the crop. In the second year, moderate productions of wheat (2610 kg ha^{-1}) and raga (*Brassica* sp.) (2000 kg ha^{-1}) were obtained [58].

Using the most common technique, irrigation water and drainage system, for reclamation of the salt-affected soils, the results of an investigation carried out by Millette et al. [77] demonstrated the ability of fall irrigation to leach salts from the surface soil during a period of low consumptive use, which could lead to reclamation. Long-term monitoring would be required to determine whether a further and permanent decline in salinity could be achieved.

Concerning other reclamation materials and techniques, results of Jones et al. [57] indicate that acid whey is effective in reclaiming sodic soil by lowering ESP, SAR, and pH and by improving infiltration rate. Rao and Leeds Harrison [104] used simulation models for desalinization of a drained two-layered saline soil using surface irrigation for different water management practices to increase leaching efficiency. Based on image elements and their correlation with the ground features, Rao et al. [101] suggested categorizing sodic soils in moderately and strongly sodic groups. The delineation thus made would help the execution of a reclamation program for sodic soils at the study sites. Abdel-Hamid et al. [1] monitored soil salinity in the northern Nile delta Egypt by using data collected via landsat and geographic information system (GIS). The collected data were used in making recommendations for reclamation of the saline soils of the Nile delta area.

The vast area of salt-affected soils still remains a burden for the societies, particularly the undeveloped countries, in need of adequate resources to reclaim them with the available technology involving initial heavy investments. The process of degradation, which has been due to reckless destruction of vegetation, can be reversed by reestablishment of vegetative cover, which results in slow but definite improvement in such soils. This phenomenon has been demonstrated a great deal by various parameters influencing the soil welfare in several investigations which show a positive sign of improvement both in terms of physical and chemical properties of the salt-affected soils. Such soils should, therefore, be brought under any type of vegetation (i.e., sod, shrub, tree) cover, if not found economical for regular farming and growing agronomic crops, and taken care by the community for posterity [117].

Even by the execution of the reclamation processes, nutrient status and their behavior in salt-affected soils (i.e., saline–sodic and sodic soils) during reclamation by crop rotation and chemical amendments requires a comprehensive assessment. This is because, usually, during the leaching process of the soluble salts and the exchangeable sodium, some soil nutrients are also lost and leached out of the soil. In this regard, several investigators [28,36,98,127,145] have studied nutrient status and behavior during the reclamation processes. Swarup et al. [127] reported the effect of gypsum on the behavior of soil phosphorus during the reclamation of a sodic soil. According to Bhojvaid et al. [28], soil nutrient status under the tree plantation was higher than that of the non-sodic farm soil. This finding confirms that successful tree plantation may restore the productivity and fertility of highly degraded sodic soils.

Regardless, the techniques used in reclamation of salt-affected soils, post-reclamation management practices, i.e., proper choice of crops, crop rotation, method of irrigation, quality and quantity of water used for irrigation and reclamation, fertilization, and the economics of reclamation must be taken into consideration and followed to achieve successful results.

1.7 CONCLUDING REMARKS

In this chapter, information has been given on the important functions of the soil in relation to soil-originated stress factors for plant and crop growth and development as well as a little more detailed information of particular problems related to salt-affected soils, their formation and reclamation.

The properties of the stress factors for plant and crop growth originating in soil are diverse and multisided. We know comparatively little about the up-to-date orientation and, particularly, for finding methods to improve the situation and ensure better plant and crop growth and development. Therefore, target-oriented studies of the different kinds of soil-originated stress factors for plant and crop growth and development are necessary so that the complex correlations and actions in the soil–plant–water system can be disclosed with the purpose of a better characterization of stress factors on the one hand, and improving the environmental and production conditions on the other hand.

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