Chapter 17
Soil Salinity and Sustainable Agriculture

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Abstract Climate change is the major cause of environmental stresses, which badly affect agricultural crops. Abiotic stresses such as heat, drought, and soil salinization, among this soil salinity, are the main problem that is very dangerous to global food security and environmental sustainability. Soil salinity causes osmotic stress, led to an imbalance of nutrient uptake, and disturbs plant growth. It is necessary to overcome this problem through different approaches like the use of compost, UV radiations, nanotechnology, integrated agro-farming systems, salty farming combined with subsurface drainage, tolerant bacteria combined with cultivars of tolerant plants, and other emerging reclamation strategies. This chapter focuses on the strategies in order to restore agricultural sustainability and ensure global food security in the face of climate change leading to an increase in soil salinity.

Keywords Soil salinity · Sustainable · Strategies · Compost · Priming · Hormones

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1 Introduction

Abiotic stress is the term used to describe how environmental factors negatively affect plants in a particular environment. Drought, salt, very low or high temperatures, and others are some of the stresses. Abiotic stress causes changes in a plant's morphology, physiology, biochemistry, and molecular structure that are harmful to its growth and productivity (Balal et al. 2016). Numerous genes that are activated by abiotic stress increase the concentration of a number of proteins and metabolites, some of which may have a role in the body's ability to defend itself against different stresses (Wasaya et al. 2021). Plants are directly affected by many environmental conditions, which result in changes to their morphological and anatomical characteristics (Tanveer et al. 2012; Tripathi et al. 2017). It has been stated that abiotic stress, such as water stress, flood, and heavy metal, causes about 50% of crop loss. Any external biotic (herbivore) or abiotic factor that decreases photosynthesis and makes it difficult for plants to turn energy into biomass is stress (Mustafa et al. 2022). The production of food must increase by 70% to feed the world expanding population. To meet the growing need for food, reducing agricultural losses caused by numerous environmental stresses is a serious challenge (Crist et al. 2017) Salinization reduces the growth of the crop and yield. The stability, development of bioenergy, and yield of basic food crops are significantly impacted by the primary abiotic stresses like excessive salt, water stress, cold, and heat up to 70%. Salt stress produces toxic minerals on plants such as Na^+ and Cl^-. It has been established that soil salinity predated agriculture and humans, but the issue has only recently arisen as a result of agricultural methods like poor irrigation (Shahzad et al. 2018; Giordano et al. 2021). Low soil water is one of major problems in the world. Among various effects of drought on plants, the first is the prevention of cell growth and division. This has an impact on normal physiological and chemical activities, such as ion absorption, respiration, photosynthesis, translocation, and nutrition metabolism. This inhibition can impact seed germination and the reduction of cell elongation during the early phases of plant growth. Lack of water inhibits leaf growth, which lowers photosynthetic area and pigments (chlorophyll *a* and *b*). Additionally, reactive oxygen species (ROS) production sets up oxidative damage in thylakoids. Chlorophyll and carotenoids in plants are affected, and the core complexes of photosystems I (PSI) and II (PSII) degrade as a result and inhibit crucial photochemical activities (Shahid et al. 2014; Guidi et al. 2017). Heat stress occurs at multiple time scales and with varying levels of severity and duration (Ishimaru et al. 2016). Heat stress has significant deleterious effects, especially on crops throughout the thermally sensitive developmental phases of early establishment, flowering, and gametogenesis (Jagadish 2020; Mahmood et al. 2022).

2 Sustainable Agriculture

Sustainable agriculture is a crucial component of world development (Janker et al. 2018). Three distinct views, such as those of economic stability, social stability, and environmental balance, must be used to approach the idea of sustainable agriculture (Farooq et al. 2019). Achieving the Sustainable Development Goals (SDG) depends on preserving and enhancing the sustainability of deteriorating irrigated drylands (UNDP, 2017). It has been documented that agronomic advances are beneficial for raising specific parameters (Devkota et al. 2015). However, because salinization impacts soils, crops, and the climate, a thorough assessment of innovations and technology is required to ascertain whether they have the potential to boost the sustainability of agricultural production (Chattha et al. 2017; Hopmans et al. 2021). Multiple sustainability indicators should be systematically quantified and compared, as various cropping systems, crops, and agronomic management techniques. This will give recommendations for adaptation and future steps to enhance the sustainability of deteriorating irrigated drylands. Additionally, in many situations, combining simulation, experimental, and multi-criteria techniques is required to increase sustainability. CA-based techniques (no-tillage, crop rotation, and residue retention) could improve the sustainability of crop production in salinity-affected irrigated drylands in Central Asia. These techniques were paired with water-saving nitrogen fertilizer rates and alternative wet and dry (AWD) irrigation techniques (Devkota et al. 2022; Mukhtar et al. 2022).

3 Soil Salinity

In order to feed the growing world population, which is expected to reach over 9.8 billion people in 2050, the soil is a crucial resource (UN 2020). Too much salt in the soil has made it saline, which is dangerous for both the environmental health and agriculture outputs (Díaz et al. 2021; Wei et al. 2021). Loss of soil fertility, changes to the properties of the soil, and detrimental effects on the environmental functions of the soil are all caused by saline buildup in the lower area or soil surface (Gorji et al. 2020). Saline–alkaline soils have high salt concentrations, pH levels, and Na concentrations. Salinized soils have electrical conductivity values of more than 4 dS m^{-1} and ESP greater than 15. Acidic soils have similar values of EC less than 4 dS m^{-1}, ESP greater than 15, and pH higher than 8.5, whereas alkaline soils have the opposite values of pH (Qamar et al. 2013; Seifi et al. 2020).

The main cause of the alkaline soil high pH is a high carbonate concentration (Decock et al. 2015). As a result, increased salinization levels cause the loss of the soil resources that are now accessible, which has an impact on agricultural growth and ecological well-being (Kumar et al. 2020). There are two main factors that contribute to soil salinity, i.e., natural (primary salinization) and anthropogenic activities (secondary salinization). The main natural sources of soil salinization are

Table 17.1 Distribution of salt-affected regions around the globe (Million ha) (Shahid et al. 2018)

Area	Sodic soil	Saline soil	Total	Percent
Africa	26.9	53.5	80.4	8.60
America	69.3	77.6	146.9	15.8
Australasia	340.0	17.6	357.6	38.4
Europe	22.9	7.8	30.8	3.30
Asia	121.9	94.7	316.5	33.9

constituent elements, physical or chemical weathering of minerals, and marine water intrusion (Ramos et al. 2020). Poor drainage conditions exacerbate the conditions of manmade salinization (Zain et al. 2017; Manasa et al. 2020).

Saline soils are soils with salt concentrations that impede plant growth (ECe > 4 dS m^{-1}). Salt stress refers to the effects that these salt accumulations have on the development, production, and seed quality of plants. Problems including improper agricultural land use, lack of rain, excessive evaporation, and poor drainage all cause the salinization of the land (Okur and Örçen 2020). Salinity stress is a crucial factor that lowers plant production. It is affecting 20% of irrigated soil and limiting food production by 30%. In salt-affected plants, nutritional issues and oxidative stress lead to hazardous levels of sodium and chlorine in the cell organelles and cytosol, which also have an impact on water uptake (Table 17.1; Machado and Serralheiro 2017).

The agriculture industry is essential to the nation's economy (Khan et al. 2020). This specific sector is responsible for producing close to 20% of the country's income. Its contribution to the GDP is 21%, and its employment as a whole is 43.7% of all employment. The country non-urban population, which makes up to 66% of the total population, depends on agriculture for at least some of their income (Abdullah et al. 2015; Elahi et al. 2022). 831 M ha of the world soil is influenced by salinity, of which 397 M ha is saline soil and 434 M ha is sodic soil (Kulshershthsa et al. 2022). Different natural or human-induced processes led to 4.5 M ha salt-affected areas in Pakistan (Aslam 2016). Natural processes include weathering of the original material and deposition of sea salt carried by rainfall and wind. As an alternative, human-induced activities such as irrigation using saltwater, a rise in the water table due to excessive irrigation, and poor drainage can also be considered. Because there is very little salt draining in these locations, salt builds up on the soil's surface, which is a serious danger. After soluble salts have been moved into the subsoil through leaching, a secondary consequence of soil salinity occurs where sodium is bonded to the soil due to the negative charges on clay (Zara et al. 2017; Leogrande and Vitti 2019).

According to the analysis, approximately 66.4% of the samples exhibited top 0–20 cm soil electrical conductivity (EC) values, and 72.8% showed sodium content (ESP) levels. Similar to this, 60.8% of the EC readings and 72% of the ESP values at soil depths of 20–40 cm exceeded safe limits. 56.8% of EC values and 79.2% of ESP values for soil depths between 40 and 60 cm exceeded the permissible limits (Solangi et al. 2019). The increased soluble salt content of the soil inhibits the uptake and metabolism of vital mineral nutrients for plants. The intake of vital nutrients such as P, K^+, N, and Ca^{2+} decreased due to particular ion toxicities brought on by increased salt uptake, or by excessive Na^+, Cl, or sulfate (SO_4^{-2}) ions (Yarami and Sepaskhah 2016).

3.1 Effects of Salinity on Plant

Salinity inhibits plant growth due to low osmotic potential of the soil solution and an inadequate intake of salt (Safdar et al. 2019). Plant growth is affected by salt in the soil and water for two reasons. Firstly, the presence of salt in the soil solution slows the plant's ability to absorb water, which in turn slows its rate of growth. Second, if the plant absorbs too much salt through the transpiration stream, the cells in the transpiring leaves are damaged, which could result in further growth reductions. This is called the salt-specific or ion-excess effect of salinity (Parihar et al. 2015). Plant growth may be adversely influenced by more acidity and toxicity of Na_2CO_3, HCO_3, and other anions in sodic soils. In the end, this harms plant nutrition and metabolism. High salinity and high EC of soil have a number of detrimental effects that result in plant cell dehydration, reduced growth, and even fatality in more sensitive plants (Syed et al. 2021). The reduced osmotic potential of the soil solution in saline soils has detrimental effects that can result in nutritional imbalances, ion toxicity, physiological drought, or a combination of all these issues. By building up salts in the shoots, it hinders the growth of plants and agricultural crops. Some distinct symptoms of salt-affected soils include restricted root growth, restricted flowering, marginal or leaf tip browning/burning, diminished vigor, and low crop yield (Sonon et al. 2015).

Osmotic stress, which is brought on by increased soil salinity, reduces the amount of water that plants need, resulting in physiological dryness. After these circumstances, the plant experiences ionic stress and its ionic balance degrades when an increase in Na^+ and Cl^- ions results from ionic stress in the medium, and they compete with K^+, Ca^{2+}, and Mg^{2+} leading to nutritional deficiency in plants. Osmotic and ionic stresses are the primary effects of salinity, whereas structural changes and the production of hazardous substances are the indirect effects (Fig. 17.1; Shahid et al. 2020).

Plants are impacted by salt stress due to toxicity brought on by osmotic pressures and ions. These impacts cause some unfavorable alterations in plants (Hussain et al. 2019). At the germination and seedling growth periods, plants are particularly sensitive. Many processes that are anticipated to take place naturally as the plant develops slow down or stop during these stages. Physiological dryness, sterility, stunted development, decreased leaf area, slow or absent blooming, disrupted membrane, production of the ROS, and decreased photosynthetic activity are a few more constraints that can occur. High salinity inhibits plant growth by reducing the fresh and dry weights of leaves and the shoot and root development (Hussain et al. 2019).

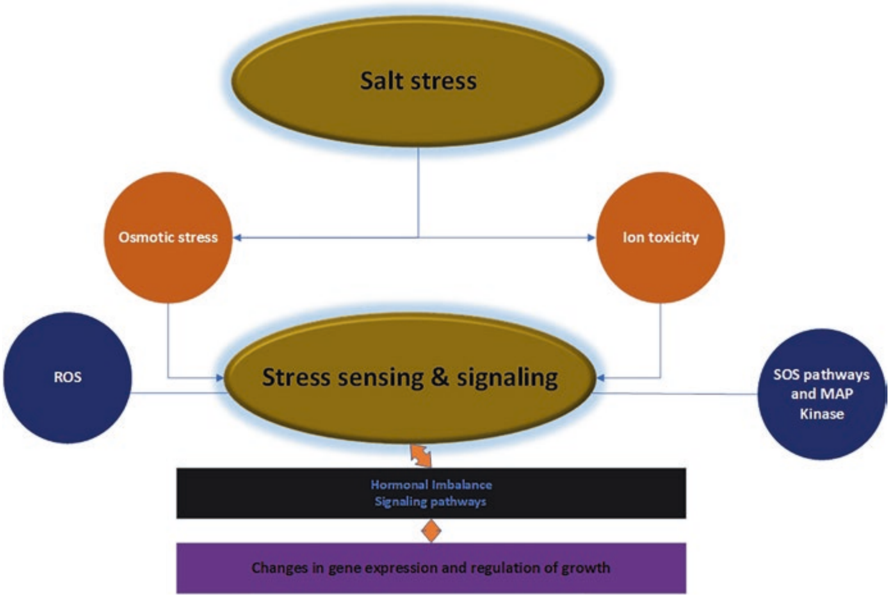

Fig. 17.1 Flow sheet diagram showing the effect of salt stress on plants (Hussain et al. 2019)

Although soluble salts are present in all soils, salty and sodic conditions cause an overabundance of salts in the root zone, which deteriorates the physical, chemical, and biological qualities of the soil. Salinity has a negative impact on plant growth, which is controlled by environmental factors such as the growing season, temperature, humidity, light, air pollution, and plant characteristics like growth stage, species, and variety. Soil factors include salinity level, moisture content, heating rate, and levels of heavy elements (Zamin et al. 2019).

4 Approaches to Mitigate Soil Salinity

4.1 Use of Compost

Municipal solid waste compost and green manure compost increase soil salinity but subsequently noticeably decrease it over time (El Azzouzi et al. 2019). Composting techniques for recovering salty soils have included a mix of sugarcane compost and green waste compost. Since there were salts that are dissolved in the compost and there was not enough flushing initially, this enhanced the soil EC over the first 100 days. The replacement of the Na^+ with Ca^{2+}, in soil exchange places and leaching of the solute, however, caused the EC to drop to 2.8 from 16.65 dS m^{-1} after 120 days, increasing the soil organic carbon content by 34.6% (Singh et al. 2019).

4.2 Phytoremediation

Phytoremediation is a widely used process in which we use plant species to reduce the salinity of the soil like *Lycium chinense*. Agroforestry and halophytic plants (*Sauda vera*) are available to overcome the salinity (Mukhopadhyay et al. 2021).

4.3 PGPB

Plant growth-promoting bacteria (PGPB) are presented in the soil rhizosphere, the area of soil around a plant root. Due to the presence of exudates of root, which serve as an attractant for a variety of organisms in soil plant, rhizosphere is rich in PGPB (Singh and Strong 2016). The improved plant growth induced by PGPB under stressful conditions is accompanied by a decrease in stress induced ethylene levels, which is mediated by antioxidative enzyme activity (Naing et al. 2021). Creating siderophores, phosphate solubilization, and nitrogen fixation to improve plant nutrition (Etesami and Beattie 2017). Exopolysaccharides are produced, which scavenge excess sodium ions and prevent their migration to plant leaves, thereby reducing sodium ion accumulation in plant roots (Qin et al. 2016; Etesami and Beattie 2017). Catalase (CAT) reduced glutathione (GR), superoxide dismutase (SOD), and ascorbate peroxidase (APX) are increased in plants to combat oxidative stress (Islam et al. 2016; Qin et al. 2016). The expression of ion transporters regulated a high sodium and potassium ratio and reduced ion toxicity (Fig. 17.2; Islam et al. 2016; Etesami et al. 2022; Mudassir et al. 2018).

4.4 Mycorrhiza

Mycorrhiza is recognized for assisting in the mobilization and solubilization of nutrients even in saline regions. There are reports on the positive effects of mycorrhiza, such as increased nutrient mobility and availability in soils (Chang et al. 2018). Furthermore, the vesicular–arbuscular mycorrhiza fungus (VAM) maintenance of a high K^+/Na^+ ratio in salty soils revealed its salt-tolerance mechanisms (Zahir et al. 2019). There are conflicting results that claim that rise in the concentration of salt in the medium reduced VAM colonization in wheat (Zafar et al. 2015; Zhu et al. 2016).

4.5 Priming

Physical techniques to boost plant growth have the potential to be used on a large scale and have environmental benefits. These techniques are an alternative to the present chemical or biological-based ones. Physical invigoration techniques are

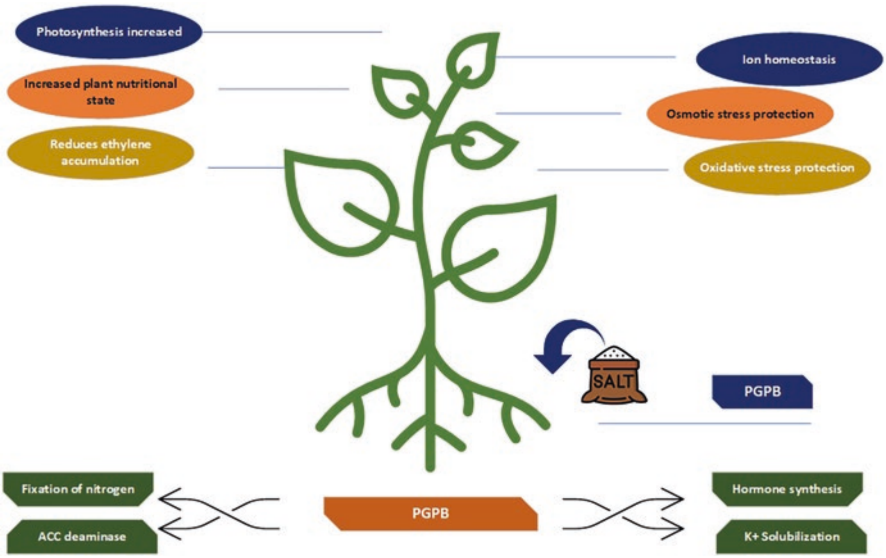

Fig. 17.2 Plant growth-promoting traits of PGPB for salinity stress tolerance in plants (Bhise and Dandge 2019)

also known as "physical priming." Physical invigoration techniques have been proven to be a successful strategy for creating new biotechnology-based solutions for the expanding seed industry (Araujo et al. 2016). According to several reports, effective pre-sowing seed treatments include the use of elements including temperature, ultraviolet (UV), and ionizing radiation (Araujo et al. 2016). In general, pre-sowing exposure to non-lethal concentrations of these physical agents has a good impact on plant health, which improves growth and yield in addition to encouraging germination. Breaking seed dormancy with pre-sowing temperature treatments is a common strategy that improves the general seed quality in batches (Liu and El-Kassaby 2015).

4.6 Use of Sulfur and Salicylic Acid

The formation of glycine betaine, photosynthetic, nitrogen fixation, proline metabolic activity, the control of the antioxidant defense system, and interactions among plants and water are only a few of the crucial physiological activities that salicylic acid controls in plants. As a result, it has been widely reported that salicylic acid protects plants from abiotic stresses (Khan et al. 2015; Wani et al. 2016). Numerous studies have demonstrated the role of salicylic acid in plant resistance to a range of abiotic stimuli, including drought, metals and metalloids, ozone, UV-B radiation, and temperature stress (Zhang et al. 2015) (Siboza et al. 2017). On the other hand, keeping the levels of plant mineral nutrients can aid plants in their ability to withstand stress (Jahan et al. 2020).

Soils contain sulfur in both organic and inorganic forms. Elementary sulfur or any of its form (sulfide, sulfate, thiosulfate) serves as a representation for the inorganically bound, which make up only 10–15% of the total sulfur. About 75–90% of all sulfur is organically bonded, which is found in organic substances such as amino acids, proteins, polypeptides, and others. Sulfur concentrations in soils are typically between 0.0% and 2.0% in humid regions, 1.0% in moorland soils, and up to 3.5% in marshland. The quantity of sulfur added by fertilizer and the content of organic matter are all important for the significant fluctuations in the total sulfur in soils (Morrison and Mojzsis 2021). The importance of the primary constituents and by-products of sulfur absorption has been well documented in plants' ability to withstand abiotic stressors, such as metals (Hussain et al. 2021), and chilling. Notably, in plants under stress, there is a strong relationship between salicylic acid and sulfur in terms of their physiological roles. For instance, the interaction outcomes of salicylic acid and sulfur significantly influenced plant growth, metabolism, and stress tolerance; exogenous SA was associated with increased GR activity and S/Cys-GSH concentration (Pal et al. 2014). Due to enhanced ATP-S and serine acetyltransferase (SAT) activity mediated by salicylic acid, cysteine and GSH levels were elevated (Nazar et al. 2015; Waheed et al. 2020).

4.7 Use of Nanofertilizer

The requirement to use excessive amounts of fertilizers has significantly increased in the current scenario of changing climate and expanding human population, but using chemical fertilizers excessively has led to the discharge of potentially dangerous compounds into the environment. In this regard, nanofertilizers have been suggested as a reliable solution to the issue (Yusefi-Tanha et al. 2020). According to reports, the use of nanofertilizers increases resistance to adverse environmental conditions, such as salinity (Adibah et al. 2020). *Zea mays* and *Arabidopsis thaliana* are subjected to saline regimes in order to investigate the impact of a betaine-rich nanofertilizer (50 mM). Under salt stress, enhanced growth characteristics and development were observed in both plant species. Another study found that tomato plants cultivated in salt benefited from the foliar application of commercial nanofertilizer based on the Lithovit VR standard (LITHO) to increase flower counts, leaf Ca^{2+}, and Mg^{2+} and decrease cellular leakage (Sassine et al. 2022). Zn-based nanofertilizer boosted growth and mitigated salt detrimental effects on plant and biomass in cotton. Si-based nanofertilizer improved the growth and output of cucumber plants, a potential worldwide vegetable crop (Yassen et al. 2017; Hussein and Abou-Baker 2018).

4.8 Ultraviolet Radiation

About 8–9% of all solar radiations correspond to the UV light component of the electromagnetic spectrum, which falls within the non-ionizing region (Coohill and Sutherland 1989). The amount of UV rising as a result of the stratospheric ozone layer thinning and research into the processes by which plants might defend themselves from this danger are growing as well. The molecular profile of these defensive responses, which are triggered by UV radiation in plants, could be utilized to develop new therapies to enhance plant sensitivity to abiotic restrictions like salinity. There is very little information on the subject of UV radiation's potential role in salinity relief (Ouhibi et al. 2014). During the investigation, two UV-C radiation doses were applied: 0.85 kJ/m² and 3.42 kJ/m². Fresh weights of roots and leaves decreased, K^+ ion absorption was hindered, and Na^+ ion concentrations increased in unprimed seeds under salt stress. UV-C therapy showed a dose-dependent impact, with its salt-mitigating effect being stronger at 0.85 kJ m^2 than at 3.42 kJ m^2. These impacts were decreased when plants were grown from UV-C primed seeds. The authors proposed UV-C priming as a quick and low-cost method for reducing stress brought on by NaCl in lettuce (Ouhibi et al. 2014). The production and concentration of phytochemicals are beneficial to health, the extending of the life span of fresh plant products, or the stimulation of plant defense against biotic stress Urban et al. 2016).

5 Conclusion

Different approaches like biological (PGPRs, fungi), chemical (NPs, sulfur), and phytohormone (salicylic acid) applications to the plants proved to be the best growth stimulator under abiotic stresses like salinity, which induced oxidative damages in plants. The medium applications of PGPRs to plants have been known to directly better plant growth and development. To address the needs of a world with increasing soil salinity problems, innovative ways for reducing saline in plants and promoting the production of crop under salinity stress are being developed. Different chemical, biochemical, and phytohormone applications are used in stress tolerance. The nanoparticles, sulfur, PGPRs, and salicylic acid enhanced plant growth under salt stress conditions. Different mechanisms are applied to tolerate the salt stress. Application in roots, priming, or foliar applications are highly effective in mitigating salt stress.

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