Chapter

Salt Stress in Plants and Amelioration Strategies: A Critical Review

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Abstract

High salt concentration in soil is a major abiotic stress, which adversely influences the growth, overall development, and productivity of crops. More than 20% of the land of the world used for crop production is adversely affected by high salt concentration. The problem of salt stress becomes a major concern when previously fertile, productive agricultural lands are salinized more profoundly as a result of anthropogenic activities along with natural causes. Therefore, this review is focused on various aspects of salt-affected soils (SAS), their effects on plants, and different approaches for reclamation of SAS to enhance the potentiality for crop production. Salt-affected soils are categorized into saline, saline-sodic, and sodic soils based on the amount of total soluble salts as expressed by electrical conductivity (EC), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), and soil pH. The inhibition of plant growth in saline soils is mainly induced by osmotic stress; reduced uptake of essential macro- and micronutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu); and specific toxicities of sodium (Na) and chloride (Cl). Sodic soils adversely affect the plant through high soil pH and poor physical condition resulting from an excessive amount of exchangeable Na. Different plants respond to salt stress in different extents. Salt-affected soils must be reclaimed to restore their productivity for increasing food production. The approaches for the management of SAS include leaching, incorporation of different organic and inorganic amendments, mulching, and development of salt-tolerant crops. The suitability of approaches depends on several considerations such as cost of reclamation, the time required, the extent of the salt stress, soil properties, availability of technology, and other environmental factors. Among different strategies, the incorporation of organic amendments is beneficial, cost-effective, environment friendly, and sustainable for amelioration of salt stress and enhancement of crop production due to the extensive roles of organic amendments in improving the soil's physical (structural stability, porosity, and permeability), chemical [pH, EC, ESP, organic matter, cation exchange capacity (CEC), and Na leaching], and biological and/or biochemical (microbial abundance, microbial activity, biomass carbon, and enzymatic activities) properties.

Keywords: abiotic stress, nutrient uptake, organic amendments, reclamation, salinity, sodicity

1. Introduction

The term stress in plants is defined as the environmental constraint that leads to the inhibition of morphological, physiological, and biochemical functioning of plants adversely affecting their growth and development [1–4]. The stresses may be biotic (pest, diseases, weed, etc.) or abiotic (soil salinity, radiation, water lodging, drought, extreme temperature, organic and inorganic pollutants, etc.) [4–12] that may act alone or in combinations, limiting the productivity of crops and food security worldwide. Salt-affected soils (SAS) cause greatest environmental abiotic stresses to plants [13–15] and cover more than 20% of the cultivated lands throughout the world [16, 17].

Salt-affected soils are grouped into saline, sodic, and saline-sodic and exhibit stresses to plants differently through various mechanisms. The principle mechanisms of salt stress in plants include osmotic effect, ionic toxicity, and nutritional imbalances [4, 15]. The increase in the uptake of Na and Cl caused by the salt constraint is attributed to the reduction in N and P concentrations that may be due to the antagonistic relations of Na and Cl with ammonium (NH_4^+), nitrate (NO_3^-), and phosphate ($H_2PO_4^-$) [18, 19]. The salt stress adversely affects plant growth by inhibiting various steps of N metabolism such as uptake, assimilation, and amino acid and protein synthesis [20]. High concentrations of Na ions at the root surface have detrimental effects on the uptake of K [21]. Because of the similar chemical nature of Na and K ions, Na has an adverse effect on K uptake by the root specifically through high-affinity potassium transporters (HKTs) and nonselective cation channels (NSCCs) [22, 23]. Similar to K, the uptake and transport of Ca and Mg can also be adversely affected by the high concentrations of Na commonly found in saline soils, resulting in lower Ca:Na and Mg:Na ratios in plants [24]. The concentration of micronutrients in plants may be increased, decreased, or remain unaffected under salt stress depending on the plant type, tolerance of plants to salinity, macro- and micronutrient concentrations in soil, pH of the soil solution, the adsorption phenomena on the surface complexes of mineral and organic particles, and different environmental conditions [1, 25].

The approaches for the management of SAS include removal of salts from the root zone through leaching, incorporation of organic and inorganic amendments, mulching, maintaining groundwater table, and cultivating crops tolerant to salt stress [26, 27]. In salt-affected areas, different methods are applied to remove excess soluble salts from the root zone of plants to improve crop growth and production. Scraping, flushing, and leaching are most commonly used, but these methods are found to be very expensive [28]. The application of organic amendments is effectively being practiced to ameliorate physical, chemical, and microbial complications associated with SAS. Organic amendments help to flocculate mineral particles to organic polymers because of their bonding or adhesion properties [29], resulting in a good structural stability, which is a precondition to maintain an appropriate soil structure. The application of organic matter to SAS can improve the aggregate stability and porosity, resulting in increased Na leaching and decreased exchangeable sodium percentage (ESP) and electrical conductivity (EC) values [30]. Several studies reported a significant increase in the soil microbial and enzymatic activities in SAS as a result of organic matter incorporation [31–33]. Salt-affected areas are increasing globally with the intervention of human activities and natural events. With the increase in salt-affected areas and population worldwide, the net cultivable land is decreasing, pushing enormous pressure on food security. It is pertinent to study how SAS harms plant growth and productivity as well as the strategies to ameliorate SAS by improving their physical, chemical, and biological conditions for the sustainable production of crops. Therefore, this chapter is arranged by compiling the existing knowledge in the literature in such a way that will demonstrate plant responses to salt stress, especially the uptake and accumulation of essential nutrient elements. Besides, different approaches that can be practiced for the amelioration of SAS have been discussed with the aim to improve soil health and boost up crop production in sustainable ways for ensuring food security worldwide.

2. Salt-affected soils: a brief preview

Understanding the differences in properties among SAS is important for proper reclamation and management. Salt-affected soils are categorized into saline, sodic, and saline-sodic groups based on the amount of total soluble salts (TSS) (measured by EC), sodium adsorption ratio (SAR; the ratio of Na^+ to Ca^{2+} and Mg^{2+} on the exchange sites of soil), exchangeable sodium percentage [ESP; the relative amount of the Na^+ ion expressed as a percentage (%) to the cation exchange capacity (CEC) or the sum of exchangeable bases], and soil pH. Based on these criteria, the classification of SAS is given in **Table 1**.

The pH of sodic soils is usually greater than 8.5, which may rise as high as 10.5. The high pH of sodic soils may be due to a greater extent of hydrolysis of exchangeable Na compared to more strongly held ions such as Ca and Mg. Upon hydrolysis, exchangeable Na contributes to high soil pH according to the following phenomenon [26]:

$$\mathrm{Na-clay-Na+H-OH} \leftrightarrow \mathrm{Na-clay-H+Na++OH-} \tag{1}$$

The increase in the concentration of OH^- ion contributes to the increase in soil pH. The limited hydrolysis of $CaCO_3$ and $MgCO_3$ causes low solubility of these salts, resulting in soil pH no higher than 8.5, while soils containing Na_2CO_3 have a pH of more than 8.5 or even 10 to 10.5 due to their higher solubility [26, 34, 35].

The processes by which saline soils are formed are known as salinization, whereas the processes that are responsible for the formation of sodic soils are called as sodification. The causes of salinization and sodification are multifactorial, and one factor that affects the salinization and/or sodification may influence the others [36]. Soil salinization and sodification are interrelated with such factors as soil characteristics; the amount and composition of salts in the soil; and the quantity, quality, and methods of irrigation [37]. Salt-affected soils are formed either by natural processes or anthropogenic activities. Natural processes are known as primary salinization/sodification, whereas human-induced processes are known as secondary salinization/sodification [38]. The main sources of soluble salts under natural and anthropogenic factors involving the development of SAS are summarized in **Figure 1**.

Types of SAS	pH	EC (dS/m)	SAR	ESP	Major cations and anions and their relative concentrations
Saline	<8.5	>4.0	<13	<15	$Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$ $Na^+ > Ca^{2+} + g^{2+} > K^+$
Saline-sodic	<8.5	>4.0	>13	>15	High content of Na^+ on exchange sites as well as in soil solution
Sodic	<8.5	>4.0	>13	>15	High Na^+ on exchange site of soil particles with little amount in soil solution

Table 1.
Classes of SAS.

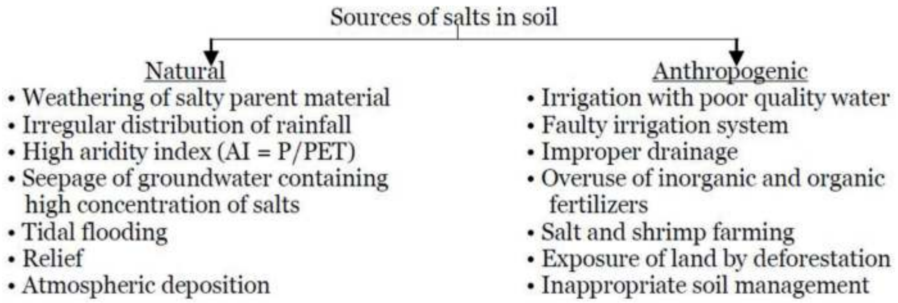

Figure 1.
Natural and anthropogenic sources of salts in soils.

Soil salinity and sodicity have contributed to the changes in land use/land cover features over the years, which are directly related to land degradation and results in many changes in the environment [39]. More than 20% of the total agricultural lands are affected by high salinity [38, 40–42], which accounts for more than 7% of the world's total land area [23, 43]. It has been reported that the majority of the SAS occur mainly in the arid and semiarid regions of Asia, Australia, and South America, covering an estimated 1 billion ha [36]. Data summarized from Abrol et al. [34] and Szabolcs [44] give an account that globally about 932 million ha areas are occupied by SAS. There are sporadic studies on the estimates in the global distribution of salt-affected areas in recent years. For the establishment of better management strategies of SAS, it is important to identify their extent and distribution in systematic ways. However, different countries assess the extent and severity of their SAS at national levels.

Soil salinity can be determined by measuring either the total soluble salts (TSS) by evaporation of a soil-water extract or by determining the EC of a soil-water suspension. In the laboratory, EC as an indicator of soil salinity can be measured by analyzing the soil suspension either in a 1:5 soil:distilled water dilution ($EC_{1:5}$) or in a saturated paste extract (EC_e). The measurement of $EC_{1:5}$ is most commonly employed from an unfiltered 1:5 soil-water suspension prepared by taking a unit of 2-mm sieved soil (usually, 5 g) and 5 units of distilled water (25 ml). The suspension is shaken for 30 min to dissolve the soluble salts and left for 15 min to settle down the soil particles, followed by the EC measurement using EC meter after necessary calibration [45].

3. Mechanisms of salt stress in plants

Though all soils invariably contain soluble salts, under saline and sodic conditions, excess salts in the root zone deteriorate the physical, chemical, and biological properties of soils to such an extent that the crop growth is adversely affected [46]. The adverse effects of salinity on plant growth depend on plant factors such as growth stage, species, and variety; soil factors such as temperature and moisture, degree of salinity, and presence of heavy metals; and environmental factors such as growing season, temperature, humidity, light, pollutants in the atmosphere, etc. [47–52]. Based on the degree of salinity and associated effects on the plant growth, the saline soils can be classified from nonsaline to very strongly saline (**Table 2**).

The mechanisms of how the SAS distress plant growth are shown in **Figure 2**. Under saline environment, the inhibition of growth is mainly induced by the physiological and biochemical disturbances resulting from osmotic stress; changes in the uptake of mineral nutrients such as N, P, K, Ca, and Mg; and specific ion toxicities

Classes of saline soils	**EC_e (dS/m)**	**Salinity effects on plant**	**Yield loss (%)**
Nonsaline	0–2	Salt effects are negligible	0
Slightly saline	2–4	Yields of only sensitive crops may be restricted, and the yields of most of the crops are not likely to be affected	20–30
Moderately saline	4–8	The yields of most of the crops are likely to be hampered	30–60
Strongly saline	8–16	Most of the crops are likely to be affected, while the yields of only tolerant crops are satisfactorily	60–100
Very strongly saline	>16	Only limited tolerant plants can sustain	100

Adapted and modified from Shin et al. [53].

Table 2.
Soil salinity classes and associated effects on plants.

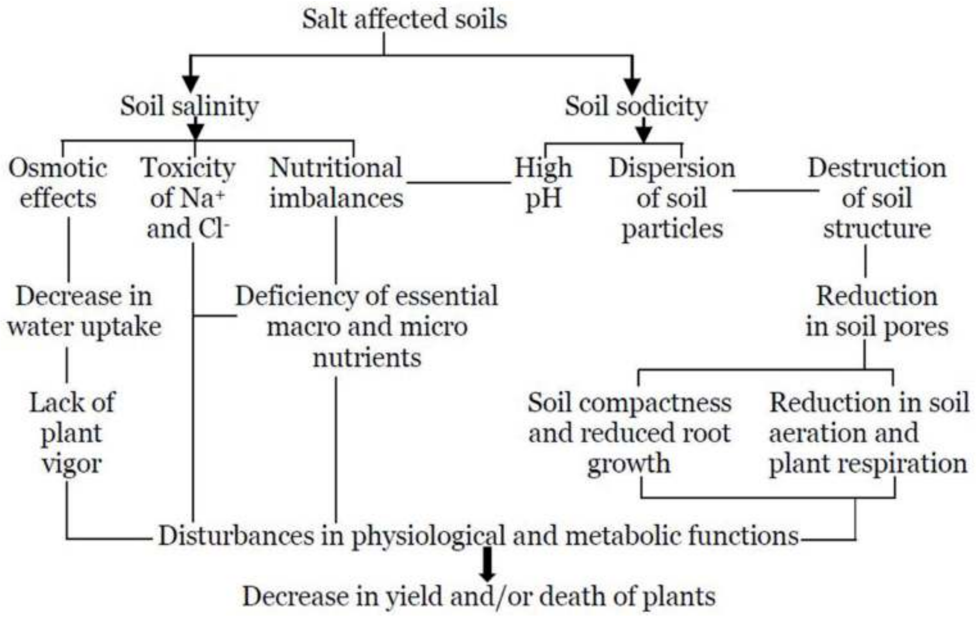

Figure 2.
Mechanism of salt stress in plants.

such as Na and Cl [54–57]. Plants containing approximately 0.25–0.5% Na in leaf tissues on dry weight basis may exhibit toxicity symptoms such as necrosis and burns of leaf edges [1, 58]. When the salt concentration in the soil is equal to that of the plant, there is no net movement of water. But when the salt concentration in the soil solution is greater than that of the plant, water moves from the plant into the soil causing physiological drought [59, 60]. To counteract the low osmotic potential of the soil solution, plants accumulate organic and inorganic solutes to reduce the osmotic potential inside the cell. Maintenance of such osmotic adjustment requires a considerable expenditure of energy, resulting in reduced growth [35]. Besides direct effects of SAS through osmotic stress and nutritional imbalances, the growth of plants may be adversely affected by a high content of exchangeable Na relative to Ca and Mg on soil particles which leads to the breakdown of soil structure, resulting in decreased porosity, permeability, hydraulic conductivity, and aeration in the vicinity of plant root [35, 41].

The adverse effects of salts are first expressed by the inhibition of growth and other physiological symptoms. Salt stress has been found to negatively affect the biomass of cabbage, *Brassica oleracea* [19]; cotton, *Gossypium hirsutum* [61]; Jerusalem artichoke, *Helianthus tuberosus* [62]; pistachio, *Pistacia vera* [63]; poacea, *Catapodium rigidum* [15]; rice, *Oryza sativa* [64]; saltmarsh grass, *Spartina alterniflora* [65]; strawberry, *Fragaria ananassa* [66]; tomato, *Lycopersicon esculentum* [64]; and wheat, *Triticum aestivum* [67].

The capacity of roots to transport nutrients and water to shoots is restricted due to abiotic stress, adversely affecting the functional balance between roots and shoots, which results in lower shoot:root ratio [68]. The leaves of plants are the most sensitive organs and greatly affected, while the roots are reasonably less affected when exposed to high salinity [69]. However, all plants do not respond to salinity to the same extent. Different crops exhibit a broad spectrum of responses to salt stress.

4. Salt stress on nutrient uptake of plants

Though the most common cations found in SAS are Na^+, Ca^{2+}, and Mg^{2+}, accompanied by anions Cl^-, SO_4^{2-}, and HCO_3^-, these soils are mainly dominated by Na^+ and Cl^- [35, 45, 70]. Nitrogen, P, K, Ca, and Mg play important physiological functions in plants, and their replacement by Na and Cl may lead to nutritional imbalances [47]. For the optimum growth and yield of crops, an adequate and balanced supply of mineral nutrients is essential [42]. High contents of Na and Cl in the rhizosphere can interfere with the uptake of essential elements, leading to their deficiencies or imbalances [71, 72] through the processes of fixation, adsorption, and transformation in soil [18]. The effects of high concentrations of Na and Cl on the uptake of essential elements by plants are outlined in the following subsections.

4.1 Nitrogen

Nitrogen is a major constituent of the nucleotides and proteins of all micro- and macroorganisms [9, 73]. It is considered as one of the limiting factors and is required in large quantities compared to other essential nutrients for the growth, yield, and quality of crops [74–77]. In general, the total N content in the plow layer of mineral soils ranges from 0.05 to 0.2% corresponding to approximately 1750 to 7000 kg N/ha, and in plants, it ranges from 1 to 4% on dry matter basis [77]. Nitrogen rarely exists in the lithosphere in rock deposits, and more than 90% of the total N comes from the soil organic matter [35]. It is principally taken up by plants in the forms of NO_3^- and NH_4^+ [61]. As a consequence of high salinity, the uptake and assimilation of NH_4^+ and NO_3^- are inhabited by excessive concentrations of Na and Cl. The uptake of other essential nutrients may be disturbed due to the inhibition of N metabolism as the presence of N in the growth medium stimulates the uptake and assimilation of other essential nutrients [77]. Decreases in N uptake may be a physiological response of plants under salt stress [78].

Salt stress was found to strongly inhibit the uptake and accumulation of N in different plant parts of green chireta, *Andrographis paniculata* [14]; cabbage, *Brassica oleracea* [19]; canola, *Brassica napus* [78]; cotton, *Gossypium hirsutum* [61]; gray poplar, *Populus* × *canescens* [20]; saltmarsh grass, *Spartina alterniflora* [65]; sesame, *Sesamum indicum* [79]; and wheat, *Triticum aestivum* [67]. However, the uptake and accumulation of N in response to salt stress depend on different plant and soil factors [80]. Kanagaraj and Desingh [79] observed variations in foliar N among different varieties of sesame, where the maximum reduction was found at the highest dose of NaCl.

The decline in the uptake of N by plants could be due to the increased uptake and accumulation of Cl. The antagonistic relationship between the uptake of NO_3^- and Cl^- was found in rice, *Oryza sativa* [64]; cabbage, *Brassica oleracea* [19]; and barley, *Hordeum vulgare* [81, 82]. High soil salinity was found to increase the concentration of Cl in the different plant parts of cotton, *Gossypium hirsutum* [47]; cowpea, *Vigna unguiculata* [72]; and poacea, *Catapodium rigidum* [15]. However, the accumulation of Cl is regulated by the duration of salt stress as well as the phase of the plant life cycle [83]. As a consequence of high salinity, the uptake of NH_4^+ can also be reduced. It was observed that the decreased uptake of NH_4^+ in plants was accompanied by an increased Na^+:NH_4^+ ratio in the growth medium [20].

Several studies reported inhibited accumulation of nutrients with decreasing water uptake under salt stress [15, 64]. The effect of salt stress on N metabolism varies depending on the forms of N applied [20]. Botella et al. [67] reported that the increased concentration of NaCl in the root medium decreased the net uptake of N more profoundly in NO_3^- compared to the NH_4^+ form when their compounds were incorporated as the source of N, which was assumed to be a reason for the greater affinity for NH_4^+ compared to NO_3^- under the saline environment. Similarly, Saud et al. [84] found higher N content, N isotope abundance, and relative water content in both roots and leaves of Kentucky bluegrass, *Poa pratensis*, in $^{15}NH_4^+$ compared to the $^{15}NO_3$ treatment under abiotic stress. By contrast, Dluzniewska et al. [20] observed that the net uptake of NH_4^+ decreased in poplars when exposed to increased NaCl concentrations, resulting in decreased whole-plant N content in comparison to control. Hofman and Cleemput [77] stated that NH_4^+ is more preferably taken up by plants in comparison to other forms as it does not require to be reduced before incorporation into plant compounds. On the other hand, Dai et al. [61] found better root growth and low Na content in NO_3-fed compared to NH_4-fed cotton seedlings, and they reported the superiority of NO_3-N relative to the NH_4-N source in the uptake of N under salt stress. The high salt content in soil may also interrupt the synthesis of protein in plants. Chakraborty et al. [85] observed that the uptake of N of the *Brassica* spp. decreased due to the high salt content, which reflected in the low protein levels in seeds. The physiological drought of plants, which is caused by the low osmotic potential of soil solution, is attributed to the reduced metabolism of N [18] that may result in the low protein content under saline condition.

4.2 Phosphorus

Phosphorus is the second most essential nutrient requiring 0.3–0.5% of the dry matter for the optimal growth of plants [86]. It is an integral part of nucleic acids and membrane lipids [73]. In contrast to N, the main sources of P in the lithosphere are the rock deposits [77]. Phosphorus exists in the soil solution as orthophosphate ions such as $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-} [87] and plants take up P from the soil solution in the form of $H_2PO_4^-$ and HPO_4^{2-}, although $H_2PO_4^-$ is taken up to a greater extent [88, 89]. Exposure to high salinity resulted in significant decrease in P levels in green chireta, *Andrographis paniculata* [14]; cabbage, *Brassica oleracea* [19]; canola, *Brassica napus* [78]; pistachio, *Pistacia vera* [63]; saltmarsh grass, *Spartina alterniflora* [65]; and spinach, *Ipomoea aquatica* [90]. The salt stress had been found to magnify the adverse effects on the uptake of P by plants in several studies when plants were exposed simultaneously to both salinity and drought [19, 65]. The reduction in P concentration under high salinity may be due to the competition between $H_2PO_4^-$ and Cl^- ions [18]. The accumulation of P in plants exposed to salt stress varies with the plant organs. Silva et al. [72] found a greater P content in leaves compared to roots. Conversely, Shahriaripour et al. [63] reported that the translocation of P from root to shoot was inhibited under a high saline environment.

The evidence of increased P under high salinity had also been reported in several studies. The presence of NaCl in nutrient solution resulted in an increased concentration of P content in leaves [72, 83]. Zribi et al. [15], however, demonstrated that salinity had no significant effect on both P concentration and acquisition efficiency (PAE), and they also found a higher concentration of Cl in the shoot when subjected to both salt stress and P treatment compared to salt stress only.

The uptake of P by plants under salt stress is influenced by the plant species, plant stage, degree and extent of stress, temperature, moisture, soil pH, and the prevailing soil P level [55, 83, 89]. The solubility of P may also be influenced by strong sorption-desorption processes with divalent cations such as Ca^{2+}, Mg^{2+}, and Fe^{3+} at different pH ranges because of their high sorption capacity regulating the uptake by plants [5, 87, 91].

4.3 Potassium

Potassium is an important and abundant mineral nutrient that comprises 2.6% of the earth's crust [92] and 1–10% of the plant tissue on a dry weight basis [92, 93]. It contributes to important physiological, biochemical, and biophysical roles such as photosynthesis, osmotic adjustment, and turgor maintenance [94, 95], regulating the growth and development of plants. The concentration of K in the growth medium determines the net uptake of K [13]. The seldom deficiency of K in most soils is believed due to comparatively high concentration and greater mobility [96, 97]. However, in the condition of salt stress, the plants may suffer from K deficiency as a result of Na toxicity. Both Na and K are monovalent cations with similar physicochemical properties. The hydrated ion radius of Na ion is 0.358 nm, while that of K ion is 0.331 nm [23]. Due to similar ionic radius and cationic competition for entry into the plant cells, high concentrations of Na can adversely affect the uptake and accumulation of K in plants.

Salt-affected soils led to a significant influence on K in plant tissues, either increasing or decreasing its concentration. The reduction in K content in plant tissues is one of the primary responses of plants to high Na, which ultimately causes nutrient imbalances [98]. High salt stress with increased concentrations of NaCl was found to decrease the total K and cause an increase in the Na content in *Aloe vera*, *Aloe vera* [99]; barley, *Hordeum vulgare* [100]; bean, *Phaseolus vulgaris* and *P. acutifolius* [54]; cabbage, *Brassica oleracea* [19]; cotton, *Gossypium hirsutum* [47]; green chireta, *Andrographis paniculata* [14]; maize, *Zea mays* [101]; pistachio, *Pistacia vera* [63]; poacea, *Catapodium rigidum* [15]; rice, *Oryza sativa* [102]; saltmarsh grass, *Spartina alterniflora* [65]; strawberry, *Fragaria ananassa* [66]; and tomato, *Lycopersicon esculentum* [13, 103, 104]. A positive relation of salt-tolerance capacity with Na and a negative relationship with that of K was found in saltbush, *Atriplex canescens* [105]. Besides, there is evidence that both the contents of Na and K in plants increased with the increase of salinity. The concentrations of Na and K in the above-ground and below-ground portions of Jerusalem artichoke, *Helianthus tuberosus*, were found to increase with the increasing amount of seawater application in a greenhouse experiment [62]. Similarly, the concentrations of Na and K in the leaves of cowpea, *Vigna unguiculata*, increased in salt-stressed condition and the responses differed depending on the duration of stress and leaf age [83]. Al-karaki [13] found higher translocation of K from root to shoot in tomato plants to a greater extent in the saline environment in comparison to nonsaline conditions, with the increase of K concentration in medium.

The higher concentration of Na restricts the transport of K by impairing the route AKT1 (hyperpolarization-activated inward-rectifying K channel) used for the uptake of K and, in this way, reduce the uptake of K [106]. The inhibitory effect of Na on the transport of K through channels in the membranes is probably more important in the phase of uptake of K from the soil solution than in the phase of K transport to the xylem [107]. Besides, the inhibitory effect of Na on K translocation depends on the concentration of K in solution. The effect is lower with low Na and high K levels in the medium [13, 108, 109]. However, the effects of Na on the uptake and accumulation of K can vary among species and even between varieties within such same species of *Aloe vera*, *Aloe vera* [99]; bean, *Phaseolus vulgaris* [110]; cotton, *Gossypium hirsutum* [111]; green chireta, *Andrographis paniculata* [14]; mustard, *Brassica nigra* [112]; tomato, *Lycopersicon esculentum* [104, 113]; and wheat, *Triticum aestivum* [109]. Salt-tolerant species were found to maintain a high concentration of K and low concentration of Na. High concentration of K and low concentration of Na in plants under saline environment can be considered as a good indicator for salinity tolerance [114]. The plant parts also differently respond to salt stress. Generally, a higher concentration of Na in roots relative to leaves in various plant species was explained by the high tolerance in roots in addition to reduced translocation of Na from root to leaf [1]. Different authors reported lower content of K as a result of salt stress to a greater extent in stems in comparison to leaves and roots [99, 110]. A high concentration of K in leaves is important to maintain constant photosynthesis and leaf stomatal conductance [54].

4.4 Calcium and magnesium

Calcium is the fifth most plentiful element, whereas Na is the sixth most abundant element comprising, respectively, about 3 and 2.6% of the earth's crust. Because of the greater charge density of Ca^{2+} compared to Na^{+}, it attracts more water, resulting in a greater hydrated ionic radius of 0.44 nm [48]. Calcium is an essential inorganic nutrient and plays a vital role in maintaining the structural and functional integrity of cell wall and membrane because of its ability to form intermolecular linkages [98, 113]. Considering the importance of external Ca in enduring K transport and K:Na selectivity in plants under Na stress condition, a large number of research was carried out on Na:Ca interactions. The deficiency of Ca in plants is a common indication of Na toxicity [115]. The Na:Ca ratio of plants is a good indication used to express the extent to which a plant can survive under salt stress [69]. A high concentration of Na can decrease the uptake of Ca and Mg by inhabiting their influx through roots, decreasing the extracellular binding sites of Ca and Mg in the plasma membranes [69, 116], decreasing the osmotic potential [19] under saline condition.

Increased level of Na was found to significantly decrease the concentrations of Ca and Mg in saltmarsh grass, *Spartina alterniflora* [65]. Significant negative correlations were also found between salt stress and the contents of Ca and Mg, where the ratios of Ca:Na and Mg:Na in the leaves and roots of cabbage, *Brassica oleracea*, decreased with the increasing salinity levels [19]. Similar results were reported by other authors where the salt stress resulted in an increased accumulation of Na and Cl and decreased the contents of Ca and Mg in plants [18, 117]. On the other hand, Chen et al. [47] found both higher Na and Ca in cotton leaf with increasing salt stress. Rahimi and Biglarifard [66] observed that the Ca and Mg concentrations decreased in the shoot and increased in the root of strawberry, *Fragaria ananassa*, with the increase in salinity. There were evidences from several studies that the supplemental addition of Ca increased the concentration of Ca in rapeseed, *Brassica napus* [114], and in tomato, *Lycopersicon esculentum* [113] under high salinity levels. However, the effects of salinity had been found more detrimental in conditions having different levels of drought stress [19, 65, 118].

The influx of Ca and Mg in the root and transport to the shoot can vary with the amount of Na as well as genotypes. The uptake of Ca had been found to be higher in a salt-sensitive variety of wheat, *Triticum aestivum*, at a low level of Na and the transport became lower as the concentration increased [115]. Furthermore, tolerant varieties of green chireta, *Andrographis paniculata*, contained high concentrations of Ca and Mg and low concentration of Na in comparison to sensitive accessions under high salinity [14].

4.5 Micronutrients

Micronutrients are involved in various important physiological and biochemical functioning of plants, including enzyme activation, chlorophyll formation, protein synthesis, carbohydrates, and lipids and nucleic acids metabolism [119]. Different authors reported differently in the uptake and accumulation of micronutrients such as Fe, Mn, Zn, and Cu in salt-stressed condition. Though the exact mechanism in the literature is scarce, different soil, plant, and environmental factors are believed to influence the uptake and accumulation of micronutrients in different plant parts under salt stress. The response of micronutrient concentrations in plants under salt stress was found to be variable in previous studies. The plants grown in saline soils often showed the deficiency of micronutrients such as Fe, Zn, Mn, and Cu, which was assumed to be the result of their low solubility and availability [120]. A negative relationship was found between the salt content and Cu, Mn, and Fe concentration in tissues of *Avicennia marina* (Forssk.) Vierh [49]. Chakraborty et al. [85] found a reduced accumulation of Fe, Mn, and Zn in different parts of *Brassica* spp. at the flowering and post-flowering stages when exposed to high salt concentration. Similarly, salt stress had been found to decrease the concentrations of Fe and Zn in the roots and leaves of cabbage, *Brassica oleracea* [19]. On the other hand, the concentrations of Fe, Zn, and Cu in green chireta, *Andrographis paniculata*, significantly increased though the Mn content decreased under high salinity [14]. The concentrations of Fe, Mn, and Zn increased in the above-ground part of strawberry, *Fragaria ananassa*, while their contents did not change in the root when plants were exposed to salt stress. On the other hand, while Cu content did not change in the aerial part, the concentration increased in the root as a result of salt stress [121]. Significant reduction in the Fe content in both root and shoot of strawberry was observed, while Zn, Cu, and Mn concentrations remained unaffected under salt stress [66]. The change in concentrations of Fe, Zn, and Mn was not found as a limiting factor for the growth of wheat, *Triticum aestivum*, and their contents in plants were not much affected by salt stress [25]. The response of micronutrient concentrations under salt stress differed among varieties in green chireta, *Andrographis paniculata* [14]; *Brassica* spp. [85]; and strawberry, *Fragaria ananassa* [121].

5. Reclamation of salt-affected soils

To make SAS productive, integrative soil, water and agronomic reclamation, and management approaches can be practiced. Saline and sodic soils differ in their reclamation and management practices because of their unlike complications. The problem of saline soils is mainly oriented with high soluble salt content, whereas sodic soils are associated with high exchangeable Na. The suitability of approaches depends on such considerations as cost of reclamation, the time required, the extent of the salinity or sodicity problem, soil properties, availability of technology, and other environmental factors [26]. This section will mainly focus on the existing information in the literature on various aspects, including the effectiveness and downsides of the leaching approach for removing salts as well as the application of organic and inorganic amendments as ameliorative for the restoration of SAS.

5.1 Removal of salts

Removing salts from the root zone is the first requirement to restore productivity of saline areas. However, saline-sodic and sodic soils cannot be reclaimed only by the leaching approach. Thus, to improve the growth and yield performance of crops in saline soils, the harmful concentration of salts must first be washed out from the root zone, which can be achieved by leaching, the most effective procedure for removing excess soluble salts. The efficiency of leaching to remove the salts from the soil profile depends on such factors as the initial salt content, nature of soluble salts, desired EC of soil after leaching, properties of soil, quality of water to be used for leaching, etc. [34]. The key to leaching of soluble salts is to provide an appropriate amount of water at the proper time with adequate drainage. A reliable estimate of the favorable soil moisture content is essential to alleviate the harmful effects of salinity by leaching. In general, depth of water equal to the depth of soil removes 70–80% of the soluble salts for continuous ponding, that is, 15 cm of water is required to reduce the salt content by 70–80% in the upper 15 cm of soil. However, as continuous ponding leads to reduced soil aeration and quick loss of water in coarse-textured soils, intermediate ponding or sprinkler irrigation is preferred for more efficient leaching of salts through increasing contact time of salts with water [122]. On the other hand, prolonged drying may increase the concentration of salts in soil solution, resulting in lower osmotic potential of the soil solution. Due to high permeability and less workability, a large volume of water can be leached over a shorter period in coarse-textured soils. Fine-textured soils having high CEC and organic matter require more water to remove the salts from the soil profile [123]. The desalinization of soils through leaching also depends upon the drainage condition of the soil. The application of leaching with surface drainage at shallow groundwater levels may further exacerbate salinity problems, while the subsurface drainage can sustain the groundwater depth and prevent additional salinization [124]. The role of organic amendments on the reclamation of SAS through improvements in physical properties found in the literature has been presented later in the organic amendment section. Soils having a good structure and internal drainage favor the leaching process [125]. Therefore, a judicious application of water having proper drainage at the right time is important to prevent irrigated lands from becoming saline. The leaching process is accomplished by either natural precipitation and/or artificial irrigation water containing minimum salt content and allowing the water to drain out. The salinity problem of the agricultural land may become worse if saline water is used for leaching purpose because of considerable quantities of such cations as Na^+, Ca^{2+}, Mg^{2+}, and K^+ and such anions as Cl^-, HCO_3^-, and SO_4^{2-} in saline water [126, 127].

5.2 Reclamation with organic amendments

Appropriate nutritional management is often considered feasible and cost-effective, which can lead to the better performance of plants grown in contrasting environments by reducing the adverse effects [128–130]. The application of organic manures as amendments to reclaim SAS is considered highly sustainable and commonly practiced over the last few years [29, 131]. Due to the high cost and quick release of nutrients involved in chemical fertilizers, the application of organic amendments as the substitute of chemical fertilizers or in a combination with chemical fertilizer has gained worldwide acceptance from the farmers [132]. Besides, the extensive application of inorganic fertilizer contributes to groundwater pollution due to leaching loss, and the global climate change is caused due to the emission of potent greenhouse gas such as nitrous oxide from agricultural lands [133, 134]. Though inorganic fertilizers provides easily available nutrients for plant, these are quickly lost from the soil. On the other hand, organic manures contribute to the physical and biological improvements of soil with a gradual release of nutrients. The incorporation of organic manures along with the chemical fertilizers is considered as an effective and sustainable approach for enhancing the resistance of crops to abiotic stress [135–138]. Different sources of organic materials originating from plant and animal residues such as green manure, cattle manure, poultry manure, food processing wastes, etc. are used to augment the organic matter content and nutrient status. The role of organic amendments on physical, chemical, and biological properties of soils having salinity and sodicity problems is shown in **Table 3**.

Sources of organic amendments	**Rate**	**Soil condition (pH, EC, and ESP/SAR)**	**Effects on soil properties**	**Reference**
Farmyard manure, and sewage sludge	5 and 10 t/ha	Different sites having variable PH and EC	Decreased bulk density, increased available water and hydraulic conductivity, decrease in pH, and increased organic matter and available macronutrients	[139]
Biochar, green waste compost (GWC), and municipal sewage sludge	1.0, 2.5 and 5.0%	pH: 4.04 $EC_{1:10}$: 4.91 ESP: 67.62	Increase in pH, total organic carbon, and CEC; decrease in EC, ESP, and SAR; and increase in catalase activity and acid-and alkaline phosphatase activity	[140]
Vermicompost and compost	5 and 10 Mg/ha	pH: 7.3 EC_e: 4.26	Decrease in pH and EC, exchangeable Na^+; increase in organic carbon, CEC, exchangeable K^+, Ca^{2+} and Mg^{2+}; and increased microbial C and N, and basal soil respiration	[32]
Municipal solid waste and palm waste	50, 100, and 150 t/ha	pH: 7.97 ECe: 5.13	Increased organic carbon and N; increased microbial biomass and enzymatic activities	[141]
Cow dung, and paddy husk	1 g/kg	pH: 7.86 EC_e: 24.35 SAR: 26.53	Decreased bulk density; decreased EC and SAR; and increased exchangeable Ca^{2+}	[142]
Cotton gin crushed compost and poultry manure	5 and 10 t/ha	pH: 8.0 $EC_{1:5}$: 9.1 ESP: 15.7	Decreased bulk density and ESP; increased soil microbial biomass, respiration, carbohydrate, and enzymatic activities	[33]
Green waste compost (GWC), sedge peat (SP), furfural residue (FR), and a mixture of GWC, SP, and FR (GSF) (1:1:1 by volume).	4.5 kg/m^3	pH: 7.75 $EC_{1:5}$: 3.69 ESP: 15.8	Decreased bulk density; increased total porosity; increased CEC, organic carbon, and available nutrients (N, P, and K); and decreased EC and ESP	[30]

Sources of organic amendments	Rate	Soil condition (pH, EC, and ESP/SAR)	Effects on soil properties	Reference
Cattle dung, vermicompost, biofertilizer, and their combinations	1.8, 3.7, and 5 t/ha	pH: 7.39 $EC_{1:5}$: 7.44	Decreased EC; increased organic matter and available nutrients; and increased microbial biomass carbon	[143]
Pig manure, cattle dung, chicken manure, rapeseed meal, and biochar	50 g/kg	pH: 8.29 $EC_{1:5}$: 19.35 ESP: 67.62	Decrease in pH; increase in organic carbon, K, Ca, and Mg; and increased enzyme activities such as catalase, urease, alkaline phosphatase, and saccharase	[144]
Poultry manure, commercially available organic fertilizer, reed straw, and fresh reed straw with green leaves	15 g/kg	pH: 8.44 $EC_{1:5}$: 11.61	Decreased bulk density; increased available N, water-soluble organic carbon; decreased SAR; and increased soil respiration	[145]
Straw, composted straw, fresh reed, and chicken manure	15 g/kg	pH: 7.82 $EC_{1:5}$: 6.59 ESP: 36.17	Decreased pH, ESP; increased organic carbon, CEC, macronutrient concentration; and increased soil respiration	[146]

Table 3.
Effects of organic amendments on the physical, chemical, and biological properties of SAS.

Organic amendments have profound influences on soil's physical properties. Several studies revealed that the application of organic manures decreased the bulk density [33, 147–149] and penetration resistance [149], whereas it increased the aggregate stability [150–152], total porosity [152, 153], hydraulic conductivity, and permeability [150, 154]. Soil organic matter is an important attribute of soil quality and aggregate stability, which is influenced by the inherent properties of soil such as soil type and texture [155, 156] as well as agronomic factors such as management, inputs, and nature of the organic matter [157]. Improvement in the aggregate stability is related to increased soil porosity and decreased bulk density. As a consequence of good aggregation with a concomitant increase in porosity and decrease in bulk density, soil water infiltration is facilitated causing the soluble salts to leach down, and an adequate oxygen supply is maintained in the root zone which is necessary for crop production in SAS.

The incorporation of organic amendments had also been found to improve chemical properties such as decrease in pH [27, 147, 158, 159], EC [27, 158, 160], ESP [33, 158], and SAR [27], while there is an increase in the soil organic matter [153, 161], organic carbon [132, 147, 151, 152, 159, 162–164], CEC [152, 162], total nutrients [32, 151, 161], and available nutrients [32, 132, 147, 149, 153, 159, 162, 164, 165].

The decline in soil pH resulting from the incorporation of organic amendments reported in several studies can be explained by the acidic nature of the amendments. Microbial activities resulting from the incorporation of organic materials release carbon dioxide that reacts with water to form carbonic acid, and thus contribute to lowering of the soil pH [166]. The pH of soils was also found to be increased by the addition of organic amendments in several studies [30, 33, 141, 143, 167]. Roy and Kashem [132] found that the addition of organic amendments slightly increased the soil pH initially which thereafter declined significantly with time. However, the change in pH with the addition of organic amendments depends on the initial pH of the original soil, nature of organic materials, and rate of organic matter application [32, 141]. The increase in pH is explained by the mineralization of carbon (C) and the subsequent production of OH^- ions by ligand exchange and release of such basic ions such as K, Ca, and Mg [167]. The decrease in EC due to the application of organic amendments might be a result of Na displacement from the exchange sites and washing out with soluble salts through the leaching process. Organic amendments substantially contain Ca, Mg, and K [30, 131]. The presence of Ca can contribute to the low ESP of SAS due to increased exchange of Na by Ca at the cation exchange sites of soil particles, allowing greater leaching of exchanged Na with percolating water [32, 168]. Moreover, the presence of soluble and exchangeable K can limit the entry of Na into the exchange complex due to a similar ionic balance resulting in lower ESP [169]. Furthermore, Ca improves the aggregation of soil by cationic bridges between the soil organic matter and clay particles, and thus increases the soil porosity. The greater the total porosity, the greater the leaching of the soluble and exchangeable Na ions, and the greater the subsequent reduction in soil sodicity and salinity as expressed by the ESP and EC values, respectively [30]. Salt adsorbing ability of organic amendments is also known to be considered in lowering the EC of soils [140]. The incorporation of different organic amendments in soils had often contributed to a slight increase in EC depending on the rate and duration of incorporation [139, 146]. The increase in EC after the application of organic manures could be attributed to the presence of high amounts of K and Ca [141]. The role of organic matter in increasing the CEC has already been established. Hue [170] reported the decrease in Na in soil solution due to greater CEC resulting from incorporation of organic matter. The removal of organic matter had also been found to increase the CEC of a specific soil, which could be due to the exposure of the permanent charge of the montmorillonitic clay that was blocked by the interaction of the organic matter with the clay [171].

Several studies reported a significant increase in the soil microbial and enzymatic activities as a result of organic matter incorporation. The incorporation of organic amendments resulted in enhanced enzymatic activities [31, 33, 140, 161, 164, 172], microbial biomass C [32, 143, 161, 164, 173], microbial biomass N [32, 161], soil microbial activity as expressed by basal respiration [32, 174], and nematode abundance [143]. However, the response of microbial and enzymatic activities to organic amendments differs depending on the kinds of amendments, rates of incorporation, the types of crops grown, etc. The rate of microbial respiration was found to be highest in poultry manure-amended soils compared to reed-, composted straw-, and straw-treated soils, and all the amended soils resulted in a rapid increase in respiration rate in the beginning of incorporation that decreased gradually with time [163]. Tejada et al. [33] also observed the highest soil microbial biomass C and cumulative C-CO_2 in soils amended with a maximum dose of poultry manure that was 37% higher compared to cotton gin crushed compost-amended soils. Similarly, the urease, protease, b-glucosidase, phosphatase, arylsulfatase, and dehydrogenase activities were found to be increased by 34, 18, 37, 39, 40, and 30%, respectively, in poultry manure-amended soils compared to the cotton gin crushed compost-amended soils. In another study, Liang et al. [31] found that the urease activity increased by 62.3 and 117.4%, respectively, in pig manure- and rice straw plus pig manure-amended soils in comparison to rice straw treatment alone. The author also observed that the addition of rice straw, poultry manure, and their combination increased the urease activity by 21, 96, 163%, respectively, in rice, whereas by 57.4, 93.1, and 152.5%, respectively, in barley compared to the control. On the other hand, Zhang et al. [164] found dual effects where the application of vermicompost increased the activities of dehydrogenase, urease, and phosphatases by 37–68%, 22–107%, and 3.4–56%, respectively, while vermicompost addition decreased the activities of β-1,4-glucosidase and β-1,4-N-acetylglucosaminidase by 17–53% and 24–42%, respectively. Easily decomposable organic substances such as biosolids, swine manure, and chicken manure may likely be retained in the soil over short periods, resulting in an intense and short effect, while recalcitrant, lignin-rich amendments such as woody biomass have a smaller but long-lasting effect on these soil properties [131, 175].

Several studies reported the beneficial effects of phytohormones and plant growth-promoting rhizobacteria in modifying the physiological and metabolic responses of plants to salt stress, enhancing their tolerance as well as growth and yield [2, 176–178]. Egamberdieva [179] found that the indoleacetic acid producing bacterial strains significantly increased the seedling root growth of wheat up to 52% compared to control under conditions of soil salinity. However, in different studies, the morphological and physiological growth and yield attributes of crops were found to be increased under abiotic stress when several plant growth regulators were applied in combination compared to their single dose [180, 181].

The beneficial effects of the organic amendments on physical, chemical, and biological properties of SAS greatly influence the growth, nutrient uptake, and accumulation of plants under salt stress. The application of organic amendments in SAS is considered a useful and effective way to increase soil fertility and enhance crop growth [31, 157]. The application of organic amendments in SAS increased the biomass yield of alfalfa, *Medicago sativa* [182]; barley, *Hordeum vulgare* [31]; cotton, *Gossypium hirsutum* [143]; maize, *Zea mays* [32, 159, 183]; onion, *Allium cepa* [142]; rice, *Oryza sativa* [31, 153, 184]; seepweed, *Suaeda salsa* [185]; sweet fennel, *Foeniculum vulgare* [186]; tomato, *Solanum lycopersicum* [187]; and wheat, *Triticum aestivum* [139]. The quantitative and qualitative improvements in the growth and yield attributes of crops as affected by abiotic stresses in the presence of different additives might be due to the enhanced photosynthesis, cholorophyll contents, stomatal conductance, water-use efficiency, and synthesis of metabolites [137, 188–191].

Organic manure incorporation into the SAS also increased the N, P, and K contents in rice, *Oryza sativa*, barley, *Hordeum vulgare* [31], and sweet fennel, *Foeniculum vulgare* [186]; K content in rice, *Oryza sativa* [184, 192]; and K and Ca contents in tomato, *Solanum lycopersicum* [187], while it decreased the Na uptake [31, 184, 186, 187]. Improved soil physical conditions, availability of macro- and micronutrients, and enhanced microbial activities in soil resulting from the incorporation of organic amendments lead to better growth and yield of crops under salt stress [30, 175]. Maintaining a high K:Na ratio as a result of organic manure incorporation is an important mechanism of plants to resist the harmful effects of salts and perform better growth [31, 186]. Decreased uptake of Na may be due to the action of organic matter which acts as salt-ion chelating agents detoxifying the toxic ions, especially Na and Cl [184]. The C:N ratio also determines the growth of plants by influencing the availability of nutrients, especially N. Incorporation of organic amendments having a lower C:N ratio attributes to higher N availability [147].

5.3 Reclamation with inorganic amendments

As saline soils are usually good in structure, removal of excess salts can be obtained merely by the leaching process, and in most cases, the application of inorganic amendments is unnecessary. However, in the case of saline-sodic and sodic soils, exchangeable Na must first be removed from the exchange sites of soil particles and then leached to wash out from the root zone. As sodic soils are characterized by poor soil structure and limited infiltration rate, in addition to organic materials, various inorganic amendments are used to improve the soil structure and facilitate the leaching process. The application of Ca containing salt especially gypsum along with the organic amendments in SAS, in order to replace exchangeable Na, improves the physical condition of the soil, facilitates leaching of salts, and increases crop yield, which has been previously been reported in several studies [142, 184]. The application of gypsum followed by leaching of soils enhanced the reclamation and decreased the salinity as well as the sodicity levels [193]. Khattak et al. [194] observed a decrease in the pH, EC, and SAR of leached soils and an increase in the yield of rice and wheat by 9.8–25.3% and 10–80%, respectively, in salt-affected soil as a result of gypsum application. Khosla et al. [195] reported that the use of additional quantities of water can be minimized by the application of gypsum to achieve a reduced SAR value to a greater extent. The amount of gypsum required to reclaim saline-sodic and sodic soils is based on the amount of exchangeable Na, soil texture, leaching rate, crop to be sown, solubility, and reaction rates of the amendments [34, 125]. Abdel-Fattah et al. [193] studied the effects of different size fractions of gypsum (<0.5, 0.5–1, and 1.0–2.0 mm) on the efficiency of the reclamation of SAS and found that the salinity and sodicity decreased with the increasing fineness of gypsum. Gypsum is usually required to spread uniformly in the field and is incorporated into the upper 10–15 cm of soil by 2–3 shallow plowings at least 10–15 days before planting [34].

Zeolite ($CaAl_2Si_4O_{12}\cdot nH_2O$), an aluminosilicate, had also been studied as an inorganic amendment with the aims to reclaim SAS and enhance plant growth. Zeolite can enhance plant growth and nutrient uptake by mitigating salt stress. In an experiment, Al-Busaidi [196] studied 1 and 5% rates of zeolite and found that the application of zeolite resulted in a significant increase in the biomass of barley, *Hordeum vulgare*, and increased concentration of Ca, Mg, and K in postharvest soils. Application of zeolite in the soil also increased fresh and dry weights of shoots and roots, fruit weight, and the number of achenes of strawberry, *Fragaria ananassa*, as well as the available N, P, K, Ca, and Mg of the medium [197]. Milosevic and Milosevic [198] found higher amounts of humus, total N, and available P and K in soil along with a significant increase in the shoot length and trunk cross-sectional area by the application of zeolite in combination with cattle manure and inorganic fertilizer. Zeolite is characterized by large sorption and ion-exchange capacity. As a sorbent, it has an important effect on the mobilization of heavy metals as well as micronutrients and macronutrients [199]. In the structure of zeolite, the negative charges developed through the replacement of quadri-charged silicon cations by triply charged aluminum can be balanced by the adsorption of Na under salt stress conditions. Besides, the three-dimensional framework of zeolite is made up of $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra, which are bonded together by sharing the oxygen atoms located at the corner of each tetrahedron in such a way that the framework develops voids or pores in the form of cages and channels between the tetrahedra [200]. The incorporation of zeolite into SAS thus can lead to the adsorption of Na on the surfaces or entrapment in the void spaces, resulting in decreased uptake by plants. Moreover, zeolite plays an important source of Ca (CaO, 16.0%) to the soil-plant system. The release of Ca in the root media from the Ca-type zeolite can maintain a high Ca:Na ratio in the shoot and root by decreasing the Na while increasing the Ca uptake [201]. While using zeolite as an amendment to reclaim SAS, the concentration of Na should be taken into consideration. The application of zeolite contributed to a substantial increase of Na in soil and plant [196]. Besides, in soils having low pH (below 4.2), decomposition of zeolite and concomitant placement of Al^{3+} and Mn^{2+} ions in the sorption complex may lead to increased leaching of Mg and Ca, root damage, deficiency of Mg and P, toxicity of Mn and Fe, and restricted plant growth [199].

6. Conclusion

Plants are subjected to various abiotic and biotic stresses due to natural or human interferences. Among the abiotic factors, the problems of soil salinity and sodicity occurring in arid, humid, coastal, and even in irrigated agricultural lands possess great threats to sustainable food security worldwide. Due to differences in properties of saline, sodic, and saline-sodic soils, their ways of stresses to plants as well as amelioration approaches are different. The adverse effects of salt stress on the uptake of essential nutrients by plants vary depending on the genotype, growth stage, concentration of salts in medium, etc. While salinity can be reclaimed by leaching of salts through good quality water together with a proper drainage system, saline-sodic and sodic soils cannot be reclaimed merely by leaching. The application of inorganic and organic amendments is often required to reclaim the saline-sodic and sodic soils. The incorporation of organic amendments is beneficial to reclaim saline as well as saline-sodic and sodic soils. Organic amendments contribute to the physical, chemical, and biological improvements of saline, saline-sodic, and sodic soils, enhancing the magnitude of their reclamation. Besides, organic amendments act as important sources of essential plant nutrients. Therefore, application of organic amendments in combination with the judicious application of inorganic amendments can be a better approach to improve the properties of SAS and the plant's response to salt stress for sustainable crop production and food security.

Conflict of interest

The authors declare no conflict of interest.

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