The Impacts of Salt Affected Soil on Soil and Plant Growth and Management Options with Organic and Inorganic Amendments A: Review

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Abstract
Globally, 833 million ha of soils are salt-affected. Approximately 20% of the world's cultivated lands and 33% of irrigated lands are salt affected. Soil salinization is spreading at the rate of 1–2 million ha year- [1] globally affecting a significant portion of crop production and making land unsuitable for cultivation. Salinity problems occur under all climatic conditions and can result from both natural and human-induced actions. Generally speaking, saline soils occur in arid and semi-arid regions where rainfall is insufficient to meet the water requirements of the crops, and leach mineral salts out of the root-zone. Salt-affected soils are characterized by the presence of sodium, calcium, magnesium, chlorides, sulfates, carbonates, and bicarbonates at elevated concentrations. However, based on sodium ion and salt concentration, salt-affected soils are categorized into saline, sodic, and saline–sodic soil. Soil salinity is a major problem which can reduce soil microbial community, enzymatic activity, respiration rate of soil, and the bacteria growth of the soils. Salinity negatively influences almost all plant processes including plant growth and plant structure, through biochemical and physical disturbances, ionic imbalance and toxicity, nutrient deficiencies, and osmotic and oxidative stresses. One of the primary effects of salt-affected soil on grain yield is reduced water availability. High salt concentrations in the soil create an osmotic imbalance, making it difficult for plants to absorb water. Soil amendments that have been studied for the reclamation of salt-affected and acid sulfate soils can be divided into two main categories, namely, inorganic and organic amendments. Gypsum, iron sulfate chloride, and sulfuric acid are the widely applied inorganic soil amendment agents having proven reclamation potential for salt-affected soils. Whereas, organic amendments like organic matter, biochar, compost, vermicompost and bio-fertilizers application is anther options for reclamation of salt affected soils.
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Introduction

Plants are encountering several environmental adversities caused both by living and non-living factors, with the former known as biotic stress and the latter as abiotic stress. Various stress factors have been found in almost all environments and climatic conditions, but salinity stress seen in plants growing under arid and semi-arid conditions should be given priority. Soil salinity is a phenomenon that negatively affects the agricultural production, because it sensibly reduces the crop yields. Moreover, when soil salt concentration is very high, it makes the soil totally unproductive. In arid and semiarid regions, soil salinity is a key environmental restraint that impacts crop sustainability and productivity. The application of amendments and fertilizers containing higher salt proportion and using low-quality water for irrigational purposes raise serious concerns to the cultivating areas (Bortolini *et al.,* 2018).

Soil salinization is a global problem that has affected 833 million ha of agricultural land in over 100 countries. Globally, 833 million ha of soils are salt-affected. Approximately 20% of the world's cultivated lands and 33% of irrigated lands are salt affected. Soil salinization is spreading at the rate of 1–2 million ha year- [1] globally, affecting a significant portion of crop production and making land unsuitable for cultivation. It is well known that soil salt accumulation leads to lower soil microbial diversity and biological activity and lower fertilizer use efficiency, which further inhibits crop growth and even the green development of agriculture. Salinity problems occur under all climatic conditions and can result from both natural and human-induced actions. Generally speaking, saline soils occur in arid and semi-arid regions where rainfall is insufficient to meet the water requirements of the crops, and leach mineral salts out of the root-zone (Ayars *et al.,* 2018). The association between humans and salinity has existed for centuries and historical records show that many civilizations have failed due to increases in the salinity of agricultural fields. Soil salinity undermines the resource base by decreasing soil quality and can occur due to natural causes or from misuse and mismanagement to an extent which jeopardizes the integrity of soil's self-regulatory capacity. The world's population grows significantly every day to feed the increasing millions, researchers are attempting to develop modern, effective inorganic and organic options to reduce salinity stress and boost crop yields. This review concern on the impacts of salt affected soil on soil and plant growth and management options to alleviate salinity problems (Zaman *et al.,* 2018).

Category of Salt affected soil

Salt-affected soils are characterized by the presence of sodium, calcium, magnesium, chlorides, sulfates, carbonates, and bicarbonates at elevated concentrations. However, based on sodium ion and salt concentration, salt-affected soils are categorized into saline, sodic, and saline–sodic soil. Approximately, 40% of salt-affected soils all over the world are saline soils, and the other 60% comprise sodic soils (Rengasamy, 2010).

Table.1 Classification of soil salinity based on the reaction (pH), electrical conductivity (EC), exchangeable sodium percentage (ESP), and sodium absorption ratio (SAR) of the affected soil

Type of soil	Electrical conductivity (dSm-1) of the saturation paste (ECe)	Soil pH	Exchangeable sodium percentage (ESP)	Sodium absorption ratio (SAR)	Physical condition of the soil
Normal	<4.0	6.5–7.5	<15	<13	Good
Saline	>4.0	<8.5	<15	<13	Normal to poor
Sodic	<4.0	>8.5	>15	>13	Very poor
Saline-sodic	>4.0	<8.5	>15	>13	Poor

Saline soils

The predominant exchangeable cations in saline soils are calcium and magnesium. Saline soils commonly have visible salt deposits on the surface and are sometimes called “white alkali” soils. Most salts in soil solution have a positive effect on soil structure and water infltration. Therefore, water penetration is not a major concern with saline soils. Salts in the root zone can reduce crop yield by making it difficult for roots to extract water from the soil. Salts increase soil osmotic potential, causing water to move from areas of lower salt concentration (plant tissue) into the soil where the salt concentration is higher. High salt concentration in the soil can cause plants to wilt even when soil moisture is adequate (Negacz *et al.,* 2022).

Sodic soils

Sodic soils are high in exchangeable sodium compared to calcium and magnesium. EC is less than 4 dS/m and often less than 2 dS/m. Soil pH usually is greater than 8.5 and can be as high as 10 or even 11 in extreme cases. High exchangeable sodium, high pH, and low calcium and magnesium combine to cause the soil to disperse, meaning that individual soil particles act independently. The dispersion of soil particles destroys soil structure and prevents water movement into and through the soil by clogging pore spaces. Sodic soils often have a black color due to dispersion of organic matter and a greasy or oily-looking surface with little or no vegetative growth. (Leogrande and Vitti, 2019).

Saline-sodic soils

Saline-sodic soils are high in sodium and other salts. They typically have EC greater than 4 dS/m (mmhos/cm), SAR greater than 13, and/or ESP greater than 15. Soil pH can be above or below 8.5. Saline-sodic soils generally have good soil structure and adequate water movement through the soil profile. They can have the characteristics of either a saline or sodic soil, depending on whether sodium or calcium dominates (Negacz *et al.,* 2022).

Causes of salt affected soils

Primary salinity

Primary salinity is caused by naturally occurring salt deposits mostly in arid and semiarid areas. Some salt soils are released from weathering saline parent rocks. Also when precipitation is insufficient to leach ions from the soil profile and transport the salts away from the root zone and when there is high evaporation rate salts accumulate in the soil and soil salinity can result this way too. Poor drainage is another factor that usually contributes to the salinization of soils, it is the most common cause, and it may involve the presence of a high ground-water table or low permeability of the soil. The high ground-water table is often related to topography. Therefore, there are drainage basins that have no outlet to permanent streams. The drainage of salt-bearing waters away from the higher lands of the basin may raise the ground-water level to the soil surface on the lower lands, may cause temporary flooding, or may form permanent salty lakes. Under such conditions, upward movement of saline ground water or evaporation of surface water results in the formation of saline soil. Low permeability of the soil causes poor drainage by impeding the downward movement of water. Low permeability may be the result of an unfavorable soil texture or structure or the presence of indurated layers (McFarlane *et al.,* 2016).

Secondary salinity

Natural salinity has been intensified by change in land use, which means change from more water use plant to less water use plant cause water table rise, when irrigation water quality is marginal or worse. In addition, when the drainage of the soil may not be adequate for irrigation, the ground-water table may rise from a considerable depth to a few feet of the soil surface in a few years due to irrigation. When the water table rises to 5 or 6 feet of the soil surface, ground water moves upward into the root zone and to the soil surface. Under such conditions, ground water, as well as irrigation water, contributes to the salinization of the soil. Deforestation, overgrazing, or intensive cropping, fertilizer and amendments applied to soils are another secondary salinity causes (Negacz *et al.,* 2022).

Effects of soil salinity

Soil physical, chemical and biological

Soil salinity is a major problem which can reduce soil microbial community, enzymatic activity, respiration rate of soil, and the bacteria growth of the soils. Osmotic and specific ion effects are the two basic processes of soluble salts that can affect soil microbes. Soluble salts enhance the osmotic capacity of soil water, which pull out water from the cells. Osmotic effect and specific ion effect are the two basic processes of soluble salts that can affect soil microbes (Yan *et al.,* 2015). Earth osmotic potential increases due to soluble salts. Leaking water from the cell causes the cell to shrink and can kill microbes to get water out of the soil. If the osmotic potential is low, then that condition can also make difficult to the plant roots and microbes to get water from the soil. Microorganisms play a vital role in plant productivity, soil structure and various function of soil. Microbes of soil comprise bacteria, fungi, archaea, viruses and protozoa. Microorganisms participate in ammonification, oxidation, nitrification, nitrogen fixation and other activities which lead organic matter to decompose and deliver nutrients to plants to maintain their life cycle. Microorganisms can also accumulate carbon and other nutrients in their biomass which are converted into inorganic material which can enhance soil fertility after cell death by living microbes (Yan *et al.,* 2015). Excessive salt concentrations can affect the structure and composition of soil microbiota. Since the salt-affected soils have low osmotic potential, different microbial genotypes can survive on low osmotic potential (Song *et al.,* 2022).

Plant growth

Plants show various physiological, biochemicals, molecular and morphological modifications in response to the increased salt concentrations in their environment. Salinity negatively influences almost all plant processes including plant growth and plant structure through biochemical and physical disturbances, ionic imbalance and toxicity, nutrient deficiencies, and osmotic and oxidative stresses. These, salinity induced abnormalities, causes reduced nutrient and water uptake, and compromised photosynthetic efficiency leading to decreased crop yields are potential hazards associated with salinity. Salinity reduces soil water potential, hindering water and nutrient uptake. Plants collect salts together with the water they use and often accumulate Na^+ and Cl^- ions in plant cells to toxic level. Furthermore, cellular enzyme activity can be disrupted due to ionic imbalances; nutrient toxicity and water stress. These factors lead to different responses in plants, manifested by a variety of symptoms in cells. Salt accumulation in the root zone causes the development of osmotic stress and disrupts cell ion homeostasis by inducing both the inhibition in uptake of essential elements such as K^+, $Ca2^+$, and $NO3_-$ and the accumulation of Na^+ and Cl^-. Specific ion toxicities are due to the accumulation of sodium, chloride, and/or boron in the tissue of transpiring leaves to damaging levels (Safdar *et al.,* 2019).

Effects on crop grain yield

The effects of salt-affected soil on grain yield can be significant and detrimental to agricultural productivity. Salt-affected soil, characterized by high levels of soluble salts, can have various impacts on grain yield, affecting both the quantity and quality of the harvested grains. One of the primary effects of salt-affected soil on grain yield is reduced water availability. High salt concentrations in the soil create an osmotic imbalance, making it difficult for plants to absorb water. This leads to water stress, which can result in reduced grain yield (Rengasamy, 2010). Insufficient water availability affects the growth and development of plants, leading to smaller grain size, lower grain weight, and decreased overall yield. Salt-affected soil can also cause ion toxicity in plants, particularly due to the accumulation of sodium ions. Excessive sodium levels can disrupt cellular processes and inhibit grain development. This can result in poor grain filling, reduced grain size, and lower grain weight. The toxic effects of salts on plants can vary depending on the specific salt composition and concentration in the soil, further impacting grain yield. Furthermore, salt-affected soil can disrupt the balance of essential nutrients required for grain development. High salt levels can interfere with the uptake and availability of nutrients like potassium, calcium, and magnesium. Nutrient imbalances and deficiencies can negatively affect grain yield and quality. Insufficient nutrient availability can lead to reduced grain size, lower grain weight, and decreased overall yield. The presence of salts in the soil also affects soil structure and fertility, which can indirectly impact grain yield. Saline soil can cause soil particles to aggregate, resulting in poor soil aeration and drainage. This can impede root development and limit nutrient uptake by plants, ultimately affecting grain yield (Matosic, 2018).

Management options

Soil amendments that have been studied for the reclamation of salt-affected and acid sulfate soils can be divided into two main categories, namely, inorganic and organic amendments. Gypsum, iron sulfate chloride, and sulfuric acid are the widely applied inorganic soil amendment agents having proven reclamation potential for salt-affected soils; whereas, organic amendments like organic matter, biochar, compost, vermicompost and bio-fertilizers application is anther options for reclamation of salt affected soils

Inorganic amendments

Use of Gypsum

The most suitable method is to replace exchangeable sodium with calcium, and the subsequent use of organic matter to bind the soil and improve its structure. Gypsum ($CaSO_4.2H_2O$) and lime (CaO) can both add calcium and, thus, can overcome dispersion as the calcium causes the inter particle forces to more readily hold the particles together. The calcium causes particles to form clusters (flocculates), forming a very clear puddle of water. Gypsum usually gives an immediate response as it dissolves (although it has low solubility) in water, though it leaches sooner than me. Amendments are those materials which supply $Ca2^+$ for the replacement of exchangeable sodium and furnish calcium indirectly by dissolving calcite (CaCO3), which is naturally occurring in many arid zone soils. Gypsum is reported to reduce the levels of exchangeable sodium in the soil (Sappor *et al.,* 2017). It also improves both soil-tilth and drainage, and achieves better crop production. The addition of gypsum to a soil changes the soil chemistry in two ways: i) by increasing the amount of salt which is in solution, thereby avoiding the swelling and dispersion of the clay component. This is a short-term effect which occurs as the gypsum dissolves, and ii) the calcium from the gypsum replaces the exchangeable sodium which was adsorbed onto the clay at specific sites. This process changes sodic clay to a calcium-clay. The displaced sodium is then leached into lower soil zones, below the plant root-zone. Mined gypsum (less than 2 mm particle size) of commercial grade (~ 70% purity) is commonly used for the reclamation of sodic soils (Negacz *et al.,* 2022)..

Sulfuric acid

The elemental sulfur or sulfuric acid will be beneficial for sodic soils that are calcareous (high in calcium carbonate). The sulfur will react with the calcium carbonate to form gypsum (BPMC 1996; Michael & Paul 2002). Elemental S, when oxidized by soil microbes and combined with water, reacts to form sulfuric acid (H2SO4), which reacts with naturally occurring Ca2+ carbonate (CaCO3), releasing "free" $Ca2^+$. This $Ca2^+$ in the soil solution can then exchange for Na^+ in the form of Na2SO4, which can be leached from the soil (Brownrigg, 2022).

Iron sulfate

Iron sulfate is a commonly used amendment for salt-affected soil. Salt-affected soil refers to soil that has a high concentration of salts, which can be detrimental to plant growth. Iron sulfate can help mitigate the negative effects of excess salts and improve soil conditions for plant growth. One of the key benefits of iron sulfate is its ability to improve soil structure. Salt-affected soils often have poor structure due to the presence of excess salts, which can lead to compaction and reduced water infiltration. Iron sulfate aids in flocculation, which helps to aggregate soil particles, improving soil structure and porosity. This, in turn, enhances water movement and root penetration, allowing plants to access water and nutrients more effectively (Horneck, 2007). In addition to improving soil structure, iron sulfate also enhances nutrient availability in salt-affected soil. Excess salts can interfere with nutrient uptake by plants, leading to nutrient deficiencies. Iron sulfate provides a source of iron, an essential micronutrient for plant growth. It helps to correct iron deficiencies and promotes healthy plant development. It aids in the precipitation of excess salts, reducing their harmful effects on plants by forming insoluble compounds with the salts, iron sulfate helps to immobilize them, making them less available to plants. This can help reduce the negative impacts of salt stress on plant growth and improve overall plant health (Vimal *et al*., 2019).

Chloride

Chloride is an essential element that plays a crucial role in the amendment of salt-affected soil. Salt-affected soil refers to soil that has high levels of soluble salts, primarily sodium chloride (NaCl), which negatively impact plant growth and productivity. The excessive accumulation of salts in the soil can lead to soil degradation and reduced agricultural yields. However, chloride can be used as an amendment to mitigate the harmful effects of salt-affected soil (Matosic, 2018). One of the primary benefits of chloride in soil amendment is its ability to displace sodium ions from the soil exchange complex. Sodium ions are the main culprits in causing soil salinity, as they disrupt the soil structure and reduce its permeability. By displacing sodium ions, chloride helps to restore the soil's structure and improve its water-holding capacity. This allows for better water infiltration and drainage, reducing the risk of waterlogging and improving the overall soil health. Chloride also aids in the leaching of excess salts from the soil when applied in appropriate amounts, chloride can enhance the movement of salts downward through the soil profile, preventing their accumulation in the root zone. This leaching process helps to lower the salt concentration in the soil, making it more suitable for plant growth (McFarlane *et al.,* 2016).

Organic amendments

Biochar applications

Biochar application can act as an effective ameliorant against hazardous abiotic stress, such as salinity stress, by nourishing overall soil properties directly related to Na removal. According to reports, biochar application in its various forms (composted biochars or pyroligneous solutions) can affect the enzymatic activities of salt-affected soils, which also depends on the rate and time of application of the biochar, along with the group of enzymes under study. When applied with organic matter, biochar shows the significant enhancement of soil organic matter, as well as CEC, and reduces the exchangeable Na and pH of saline soils. Biochar and fulvic acid have been found to improve the overall soil physical and chemical properties, which further adds to the multiple benefits of salt reduction, nutrient supply, water retention, and crop growth (Sun *et al.,* 2020). Biochar, used alone or in various combinations, has been found to enhance the overall physicochemical and biological properties of soil. biochar and fulvic acid can release nutrients to the soil for plant utilization under salinity stress. Biochar application has been considered a potential tool for plant nutrient availability, even under salt stress (Noori, 2021).

Vermicompost

Organic fertilizers have been used in soil reclamation and for the enhancement of soil nutrient status for quite a long time. It improves soil structure, increases mineral availability, enhances soil productivity and the quality of the produce, and has been reported as an economical approach to lower reliance on synthetic fertilizers. Organic fertilizers and their derivatives enable plants to tolerate salt stress efficiently. The cumulative activity of soil microbes and earthworms on any organic matter produces vermicompost. It is an organic fertilizer that possesses broader microbial activity and plant growth hormones and hence can be used to ameliorate the effect of salt stress in the soil–plant system. Ever-increasing environmental degradation necessitates exploring sustainable and environmentally benign approaches to mitigate the detrimental effects of salinity on maize seedlings (Kumari, 2022).

Application of organic matter

Adding organic matter is always beneficial when working with sodic soils. It can help to open up the sodic soil, improving soil structure, drainage and moisture holding capacity along with planting salt tolerant species will enhance the reclamation process. Decomposing organic matter helps stabilize calcium as well as providing channels in the soil to conduct water, and to help reduce evaporative losses. The organic matter also helps to lower the soil pH, which decreases the exchangeable sodium near the surface and it stimulates microbial activity, which promotes aggregate stability of the soil particles (Singh, 2016).

Bio-Fertilizer

BFs are one kind of fertilizer that contains living cells from various microorganisms and can transform via biological mechanisms; nutrients are converted from the inaccessible to the accessible form. Recently, many studies have described the potential of BF in salt tolerance enhancement (Brownrigg, 2022). The application of BF in wheat seedlings lessened the negative effects of salinity by increasing chlorophyll content and decreasing proline content, and improved plant growth and yield. Under salt stress, amaranth enhanced plant height and biomass production. It has also been reported that the application of BF to lavender enhanced its capacity to withstand salt stress by increasing morphological attributes and RWC, Chl a, Chl b, and total Chl content as well as its essential oil output. Similarly, BF application on wheat (*Triticum aestivum* L.), okra (*Abelmoschus esculentus* L.), yellow passion fruit (*Passiflora edulis*), cowpea (*Vigna unguiculata* L.), corn (*Zea mays* L.), and olive plants (*Olea europaea* L.) enhanced growth and yield metrics, micro and macronutrient content, and relieved salinity-related detrimental effects (Lu, 2020).

Other methods of amendments

Planting agroforestry

Physical methods, such as surface and subsurface drainage and the application of chemical amendments, are viable remedies to reclaim these soils, but they are either costly or sometimes comparatively inefficient. The agroforestry system has been identified as one of the most suitable environment-friendly soil remediation strategies against land degradation problems as the former has been found to be comprised of multiple components, such as plantation, crops, and horticultural crops, as well as animal husbandry and aquaculture. A 20-year-old tree plantation (Prosopis julifera, Acacia nilotica, Terminalia arjuna, Albizzia lebbeck, and Eucalyptus tereticornis) in alkali soil was found to be effective in the amelioration of salt in a salt-affected soil. Significant decreases in soil pH and EC levels have been reported under different plantations of varying ages (Singh, 2017).

Use of salt-tolerant crops

Crops differ widely in their tolerance to salt stress conditions. A proper choice of crops is therefore very important, considering the soil conditions. To identify promising germplasm, the limits of stress tolerance in different crops have been studied in field and under controlled conditions in pots and micro plots. Even planting or protecting natural halophyte vegetation also contributes for the further control of salinization of the soil; what is more, some of the salt-tolerant plants can be used as forage for animals and can be taken as the direct economic profit from saline lands. The claim effect of growing salt-tolerant crops in saline and sodic soils is well known indifferent salt affected areas (Singh, 2017).

Leaching

Soils rich in soluble salts can be reclaimed through dissolving of these salts and their successful leaching. This can be accomplished through flooding or ponding of water at the surface for saline soils. In general, the depth of soil leached is roughly equal to the depth of water infiltrated during leaching. In order to leach salts from a soil, an understanding about the leaching requirement (LR) concept is important. The LR is the calculated fraction (depth) or quantity of water that must pass through the root-zone in order to maintain the EC of the drainage water at or below a specified level. Some soil scientists are of the opinion that LR should be minimized to prevent raising the level of the groundwater table, and also to reduce the load placed on the drainage system (Rengasamy, 2010).

Recommendations

Soil salinity is a major global issue owing to its adverse impact on agricultural productivity and sustainability. Salinity problems occur under all climatic conditions and can result from both natural and human-induced actions. Generally speaking, saline soils occur in arid and semi-arid regions where rainfall is insufficient to meet the water requirements of the crops, and leach mineral salts out of the root-zone. Based on sodium ion and salt concentration, salt-affected soils are categorized into saline, sodic, and saline–sodic soil. Approximately, 40% of salt-affected soils all over the world are saline soils, and the other 60% comprise sodic soils. Primary salinity is caused by naturally occurring salt deposits mostly in arid and semiarid areas. Secondary saline natural salinity has been intensified by change in land use, which means change from more water use plant to less water use plant cause water table rise, when irrigation water quality is marginal or worse. Soil salinity is a major problem which can reduce soil microbial community, enzymatic activity, respiration rate of soil, and the bacteria growth of the soils. Salinity negatively influences almost all plant processes including plant growth and plant structure and impacts on grain yield, affecting both the quantity and quality of the harvested grains. To alleviate salinity problems implementing proper management option is important. Soil amendments that have been studied for the reclamation of salt-affected and acid sulfate soils can be divided into two main categories, namely, inorganic and organic amendments. Gypsum, iron sulfate chloride, and sulfuric acid are the widely applied inorganic soil amendment agents having proven reclamation potential for salt-affected soils; whereas, organic amendments like organic matter, biochar, compost, vermicompost and bio-fertilizers application is anther options for reclamation of salt affected soils.

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