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PLANT GROWTH AND MICROBIAL DIVERSITY AS STRESSED BY SOIL SALINITY WITH POSSIBLE REMEDIAL MEASURES

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ABSTRACT

Soil salinization is a continuously growing challenge worldwide, damaging the total arable land (20%) and irrigated land (33%), retarding crop production and threatening global food security. Several natural and anthropogenic factors have accelerated the soil salinization process in recent decades and made it an uncontrolled obstacle for crop production. Microorganisms perform numerous life-supporting activities, including organic matter decomposition, recycling of resources, symbiosis, resistance induction against biotic entities and ameliorating abiotic stresses. Abiotic stressors (e.g., salinity) deteriorate the soil microbial diversity, alter the ecological balance, and perturb the nutrient cycle. Several experts have reviewed the effects of salinity on soil microbial community and soil respiration under the available organic carbon sources. However, there is a dearth of studies directly illustrating the relationship between salinity and the enzymatic activities in saline soils, which is critical in harmonizing cell communications with the outer environment. Furthermore, it also defines the relationships between different members of the soil ecosystem and the equilibrium between them. Saline soils have more deteriorated enzyme activities as compared to alkaline calcareous soils. Plants and microbes play a crucial role in rehabilitating a deteriorated soil environment by mitigating the salinity stress. Around the world, many approaches (such as physical, chemical, biological, hydro-technical, etc.) have been extensively studied for soil remediation against salinity, but the synergistic approach is one of the highly recommended approaches by researchers. A synergistic approach is a collective, smart, and simultaneous application of all the available techniques to remediate saline soils. This review has discussed a balanced practice of all the components of the integrated approach to perform it sustainably. The manuscript will refine our knowledge about the current state of soil salinization, its impact on the environment and agroecosystem, and the advanced technologies useful for its remediation.

Keywords: Soil salinity, microbial diversity, remedial measures, salinity stress, plant growth

INTRODUCTION

Water scarcity, environmental pollution, and soil and water salinization increased globally at the beginning of the 21st century. For the sustainability of agriculture, available land for cultivation and the rapid increase in the human population becomes a threat to food security (Shahbaz and Ashraf 2013). High temperature, drought, soil salinity, high wind, and flood are the environmental factors responsible for lower crop cultivation and production. More harmful environmental stress is soil salinity which causes lower crop quality, production, and land cultivation (Yamaguci and Blumwald 2005). Salinity is the root zone saturation extract (ECe) of electrical conductivity (EC) at a 25 Celsius scale that exceeds than 4 dSm^{-1} and 15% of exchangeable sodium (Jamil *et al*. 2011). Saline area increases by about 10% due to poor irrigation systems, low rainfall, surface evaporation, and poor cultural practices. By 2050, it is estimated that 50% of the cultivable land will become salinized (Jamil *et al*. 2011).

Salinization of soil

Soil salinity is a part of the natural ecosystem in arid and semi-arid regions and increasing day by day. While in moist and temperate climates, soil salinization occurs on a minute scale, it usually occurs along the roadsides and saltwater marshes (Qadir *et al*. 2000; Wichern *et al*. 2006). Soil salinization is an accumulation of soluble salts in the root zone of the soil. Salts are potassium, calcium, magnesium, sulphate, chloride, bicarbonate, and carbonate while accumulation of sodium is known as sodification. When high sodium content is present in the soil, destruction of soil structure takes place because no oxygen is entering the soil, which causes stunted growth of plants. The accumulated salts affect the crop germination, nutrient absorption, water availability, density, and productivity of crops (Ahmad *et al*. 2015).

Factors of natural soil salinization and sodification

Some common factors that lead to the formation of sodification and salinization, such as salt concentration in soil and groundwater are increased by a geological factor, groundwater containing salt content bringing to the surface is due to natural factors, in the coastal zone with the action of wind salts transport to the interior, high Salts content in the irrigation water, human activities rise in water level (inappropriate drainage, the poor infiltration rate and poor distribution of irrigation water), the high salt content in industrial water contamination of soil take place and use of chemical fertilizer in poor leaching and lower drainage soils. All the salt present in the saline soil is due to the weathering of rocks from which soil came into existence. Salt-affected soils are mostly present in the irrigated area. This is due to the inappropriate management of irrigation and other practices such as the extension of chemical fertilizer and these factors make the soil more and more saline. FAO estimated that all over the world, about 250 million hectares of land are affected by soil salinity, and 10 million hectares are affected annually (Pessarakli and Szabolcs 2019). Due to their nutritive value and importance for improving the physical properties of soil, mostly nitrogen (N) organic fertilizer is useful (Garbarino *et al*. 2003). Usually, the contents of salts are ignored, which is harmful to soil quality and crop production by continuous application. Organic fertilizers reduced the secondary salinization and precipitated as a non-precise pollution source (Li-Xian *et al*. 2007).

Activities for anthropogenic soil salinization

Agriculture

Overuse of chemical fertilizers cause soil salinization (Endo *et al*. 2011). Modern irrigation techniques lead to more crop production, but the method by which irrigation is applied increases soil salinity, which causes failure of crops and causes a threat to food security.

Road salts

The freezing point of water can be reduced by the application of sodium chloride on roadsides to reduce collisions. In a cold climate application of road salts cause water and soil salinization (Litalien and Zeeb 2020). In the winter season, applied salts accumulate in snow packs and roadside soils. When the temperature increases, ice melts, which takes salts to water bodies, and when that water is applied to the soil, it increases the soil salinity.

Other sources

Steel formation, pulp, and paper production, wastes from industries, cement, manufacturing, and mining activities cause' soil salinity (Muller *et al.* 2009). Other industries including food production and textile also release many salts.

Effects of salinity on plant growth and yield

Soil salinization affects the ecological balance, soil's physical and chemical properties and also decreases agriculture crop production and ends to low economic potential (Hu and Schmidhalter 2004).

Salinization affects not only biochemical, physiological, and morphological processes but also nutrient and water uptake, seed germination and plant growth (Akbarimoghaddam *et al*. 2011). All components of plant development are affected like reproductive development, seed germination, and vegetative development. Salinity causes osmotic stress, ion toxicity, nutrient deficiency (Zn, P, K, Fe, N, and Ca), and oxidative effect on plants which lower the uptake of water. Phosphate ions are formed by precipitating with calcium ions, reducing phosphorus uptake in plants (Bano and Fatima 2009). The excessive accumulation of sodium in the cell wall causes the death of cells (Munns 2002). Salinity affects the chlorophyll content, reduces the leaf area, photosynthesis, stomata activity, and efficiency of photosystem II (Netondo *et al.* 2004). Impact of abiotic stresses on plant yield and quality is presented in figure 1. Salinization badly denatures the ovule abortion, elongation of stamen filaments, causes senescence of the embryo and inhibits microsporogenesis. Saline medium adversely affects nutritional imbalance, plant growth, osmotic stress, and salt stress (Ashraf 2004). All these given factors affect plant growth at different levels, molecular levels (Tester and Davenport 2003) and physiological and biochemical levels (Munns and James 2003). The comparison of maize root growth in non-saline and saline soil is presented in Figure 2. Many researchers explained the relationship between crop yield and soil salinity (Negrão *et al.* 2017). In dryland areas, soil salinization is a major concern for crop production (Butcher *et al.* 2016; Ramos *et al.* 2020). According to Safdar *et al*. (2019) in these areas, high temperature leads to salt buildup in the soil profile, and high evaporation rates result in osmotic stress and a negative influence on water availability. Effects of salinity levels on crop yield (Table 1)**.** According to many researchers, salinity stress at 2d S/m doesn't affect the crop yield, while sensitive plants show a reduction in yields at 2-4 d S/m. Sensitive plants such as pears, almonds, apricot, orange, cherries, plum, sugarcane, and beans have the ability to endure salinity up to 4dS/m. Salinity levels beyond 4 d S/m because of reduction in the yield except for salt tolerant crops, plants cannot be able to grow even germinate if salinity level reaches more than 16 d S/m. Moderately tolerated crops such as guava, sunflower, pineapple, cucumber, rice, grape, and alfalfa endure the salinity level up to 6 d S/m. In comparison, tolerant crops such as barley, Bermuda grass, Swiss chards, cotton, rapeseed, and wheat grass tolerate salinity up to 10 d S/m. In contrast, some sensitive plants show a reduction in decrease at 1 d S/m. Salt stress in soil initiates the drought condition, but the matter is that all halophytes are not drought tolerant (Bhatnagar-Mathur *et al.* 2007).

Salinity effects on soil microbial diversity

Environmental stress like fires, water content, and heavy metals are considered the stress factors for soil microbes. Due to stress tolerance mechanisms, a metabolic load is imposed on microorganisms which causes a decrease in the activity of cells in sensitive microorganisms (Chowdhury *et al.* 2011; Ibekwe *et al.* 2010; Yuan *et al.* 2007). Salinization with low humidity is the most regressive factor for soil flora in a dry climate. In agricultural soils, salinity stress is important due to the application of chemical fertilizers and poor irrigation practices (Rietz and Haynes 2003). Due to the transpiration absorption of water, increased salinity effects can be seen in the rhizosphere (Oren 2002; Jiang *et al.* 2007). Different cations and anions in their liquid phase and their accumulation cause salinization of soil, which affects the physical, chemical, and biological properties of soil (Shahid *et al.* 2018b; Pessarakli and Szabolcs 2019). Salinity may affect the composition of the microbial community (Asghar *et al.* 2019; Llamas *et al.* 2008). The low osmotic potential of microbial genotypes differs in their tolerance (Llamas *et al*. 2008; Mandeel 2006). Germination of fungus spores, growth of hyphae, and morphology changes take place due to low osmotic potential (Juniper and Abbott 2006). Whereas it also modulates the gene expression (Liang *et al.* 2007) and spores wall thickening (Mandeel 2006). Sodium chloride with different concentrations of total fungal count is reduced in saline soil. Actinobacteria and bacteria reduced drastically at more than a 5% increase in soil salinity (Omar *et al.* 1994). In the agriculture ecosystem, soil microbes perform many activities, improve the soil structure, degrade toxic substances, phytochrome production, and uptake of nutrients (Hakim *et al*. 2021; Jiang *et al.* 2019; Luo *et al.* 2021; Yan *et al.* 2015). Soil cultivated with cotton (*Gossypium hirsutum*), different bacteria like denitrifying, phosphate solubilizing, nitrifying, and ammonifying bacteria reduces with the increases in salinity level (Rath *et al.* 2019).

Salinity affects soil on enzymatic activities

Soil enzyme activities perform most of the biochemical transformation in soil. Some soil enzymes carry out important functions, such as enzymes acting as a catalyst for the microbial decomposition of organic matter, cycling of nutrients, and organic residue decomposition. For the transformation of different plants, nutrients, phosphates, dehydrogenase, urease, and β-glycosidase enzymes are used (Nannipieri *et al.* 1990). β-glucosidases are an important enzyme in the production of glucose and land carbon cycle, which are the important source of energy for microbial mass (Kumar *et al.* 2008). Phosphorus is considered an essential nutrient. Most of the soil phosphorus is present in organic form. The phosphatase enzyme converts the organic form of phosphorus into the plant's available inorganic forms, while in the nitrogen cycle of soil, urease is considered to predominate among the enzyme (Cookson 1999). Urease activity in the soil depends upon the soil pH and carbon dioxide concentration. The area is firstly converted into an ammonium ion then ammonia is further catalyzed by the urease. Urease and enzyme catalyze the vegetable residue in the soil. Residues convert into humus with the activity of these enzymes, and they decompose into the form of nutrients (Ahmad *et al.* 2007). Polysaccharides are hydrolyzed by enzyme amylase into their simpler form. The salts modify ionic toxicity levels, the active site of protein enzymes, microbial population reduction, and nutrients with the proper imbalance of enzyme synthesis.

Remediation techniques against salinity

Means of the prevention, mitigation, and remediation of the saline-sodic soils could be done using various physical, chemical, and biological methods. These methods are explained in their various subsections in the following.

Physical Approach

The physical approach could be divided into three subsections for remediation such as salt flushes and leaching, tillage, fertilizer, and manuring scheme.

Salt flushes and leaching

Removal of the upper salt-affected layer by a heavy machine such as a tractor-scraper machine is apparently well managed; technique, but it is not economically feasible and works for a short time (Cuevas *et al.* 2019). In this ongoing scenario of salt removal, flushing of salts with good quality irrigation, water, and draining of the surface salts from the targeted place could be cheaper than the first one (Shahid *et al.* 2018b). Cuevas *et al.* (2019) describe that leaching of the salts from the root zone by applying extra irrigation to the fields helps to neglect the capillary action from the soil due to high temperature. This extra irrigation is known as leaching fraction and must be applied during the growing season to remove the salts from the root zone. The cost of salt flushes and leaching is more, but their viability and long-term efficiency make them better than other physical methods. But if the irrigation source has a suitable amount of sodium, it may remove the calcium and magnesium ion from the soil profile and leads to the formation of sodic soils.

Conservational tillage scheme

Soil tillage is usually done for the seedbed preparation and done as a regular practice in main cultivated land. Alongside conventional tillage benefits such as soil loosing and aeration but they have many more disadvantages such as damage to soil structure, increased oxidation of organic carbon, breakdown of aggregates, decreased hydraulic conductivity, and reduced soil erosion (Blanco-Canqui 2018). In recent decades, tremendous improvement has been made in conservational tillage. Conventional tillage reduces the leaching capacity of salts, and minimum tillage, particularly zero tillage, improves leaching and negates the soil salinity (Stavi *et al*. 2021). No-tillage practices at the ends of the remaining crop residue act as surface mulches and reduce the soil salinity and sodicity (Stavi 2021; Jha *et al.* 2022).

Fertilizer and the manuring scheme

Lack of phosphorus and nitrogen, especially organic matter in the soil, causes fertility problems (Frankenberger and Bingham 1982). Remediation from the soil salinization types of organically originated materials are used such as the cover crop, manure, and different compounds are efficient by applying organic matter decrease electrical conductivity, exchangeable sodium ions and increase water holding capacity, an infiltration rate and leaching of NaCl (El-Shakweer *et al.* 1998). Salinized soil shows less productivity exploitation with proper agricultural practices and changes in organic fertilizers (Carrillo-Garcia *et al.* 2000). Adding sludge, sewage, and mesocarp-epicarp of the almond tree to salinized soil increases nitrogen, potassium, and phosphorus in the fruit of tomato and soil (Gomez *et al.* 1992), iron and magnesium concentration in rice (Swarup 1985). Adding stable manure reduces the sodium adsorption ratio (SAR) (Gaffar *et al*. 1992). Many researchers studied that salinized soils have an increment in the organic carbon content and increase in soil microbial biomass, density, and structural stability. C/N is important with respect to the decomposition of organic matter. The incorporation of rice straws with swine excrement or rice straw or swine excrement increases the activity of urease and phosphatase enzymes and the rate of respiration (Liang *et al.* 2003).

Chemical methods

At the same time, sodic soil can be restored by applying a calcium source that exchanges the sodium ion from the exchange complex, thus making the sodium ion available for leaching from the root zone of the soil. Therefore, a widely used calcium source is gypsum (CaSO4.2H2O), and their gypsum-like byproducts such as phosphor-gypsum (a byproduct of phosphoric acid manufacturing), coal-gypsum (a byproduct of coal power plants), and Lacto-gypsum (a byproduct of lactic acid and lactate manufacturing) (Amezketa *et al.* 2005).

These available sodium salts are leached by extra irrigation, applied at the time after the amendment's application. The application of gypsum rates is greatly varied and depends on many factors such as the magnitude of the sodification, environment, soil type, quality of amended materials, soil type, quality of irrigation water, underground water and parent material, and the coming variety of crops (Amezketa *et al.* 2005; Qadir *et al.* 2007).

Biological Methods

Biological or Microbial remediation

In a saline environment variety of salt-resistant microorganisms are found. Actinobacteria, spirochetes, and proteobacteria are a variety of salt-tolerant microorganisms (Grover *et al*. 2011). Physiological and genetic adaptations enhance salinity tolerance by ecological processes (Yadav *et al.* 2017). In changing environment, a microbe responds to detect the change and survive in the new conditions (Yuan *et al.* 2016). Data regarding beneficial effects of halotolerant microorganisms on plants' growth under saline conditions is presented in table 2**.** Hatton and Nulsen (1999) studied that the use of plants for the reclamation of saline soil is another type of approach. Remediation of saline soils by using plants has low acceptance because of low profitability, but it's a low-cost and most efficient method. To improve soil salinity conditions, some farmers use salt-tolerant trees, shrubs, or forage (Ravindran *et al.* 2007). Crops with a high tolerance to drought and salinity stress should be selected, and especially deep-rooted crops are selected for the plantation. That's why they uptake water from the deep ground and remediate the soil deeply (Cuevas *et al.* 2019). Among the grain crops, barley (*Hordeum vulgare* L) is highly tolerant to dry conditions and soil salinity. New barley cultivars show exceptional behavior against salinity and drought tolerance (Katerji *et al.* 2006). Among the vegetable crops, potato (*Solanum tuberosum* L.), carrot (Daucus carota), onion (*Allium cepa* L.), lettuce (*Lactuca sativa* L.), and cabbage (*Brassica oleracea* L.) are reported to have a comparatively high tolerance to moderate saline condition (de Vos *et al.* 2016). Green Liver model is presented in Figure 3. While among the forage crops, alfalfa (*Medicago sativa* L.) is known to tolerate the salinity well, with some specific cultivars that show exceptional behavior against the soil salinity. Kallar grass ((*Leptochloa fusca* L. Kunth), is a fodder crop widely used in salt-affected and water logged in Pakistan to ameliorate the saline, sodic, and saline-sodic soils (Stavi *et al.* 2021). Practices of phytoremediation for saline-sodic soil and phytoremediation species are presented in table 3.

Advances in remediation

Several techniques are used for salinity remediation. Some of them are genetic engineering of plants, genes for detoxification of metals genetic engineering of endophytic bacteria. Many researchers worked on the advances on the advances in remediation by using symbiotic microbial strain to produce tolerance in plants against salt tolerance. Brígido *et al.* (2013) transferred *Mesorhizobium ciceri* G-55 (salt tolerant) with acids gene encoding ACC deaminase. Bacteria produced higher nodulation in chickpea which resulted that symbiotically correlated plants have more ability to tolerate the salinity stress. Shultana *et al.* (2021) studied that PGPRs can play the significant role in the augmenting plant growth under salt stress condition. The "UMPRB9" produces the high amount of EPS and significant amount of biofilms. The higher amount of EPS availability producing bacteria enhances the water content and nutrient level in rhizosphere (Kalam *et al.* 2020). The EPS reduces the negative effects of osmotic stress by increasing water contents to plants, that results in more ability to tolerate the salt stress in plants (Ghosh *et al.* 2021). The advances in remediation and their benefits to plants are presented in table 4.

Food security and future perspectives

Cereal crops are the major source of food for millions of people in the world. With increasing food demand, many efforts are required for growing cereals production to fulfill the increasing food need. Salinity is major Abiotic stress in crop growth and development, which cause the failure of crop and yield reduction. Modern breeding tools and molecular markers are required to produce salt tolerant cultivars instead of time-consuming breeding approaches. Finally, most research is only made on NaCl in the soil, while other types of salts are also present in the soil. Future research should be made on other salts and their agronomic impact on crop growth and development (Alkharabsheh *et al.* 2021).

CONCLUSION

From the reviewed literature, it could be concluded that dry land salinity badly affects the soil's physical, chemical, and biological properties in arid and semi-arid regions. Rapid increment in population needs more food resources for consumption. Soil salinity harms agriculture crop production and badly denatures the soil microbial diversity and enzymatic activity. Salinity is among the brutal factors to reduce crop production by up to 50%. Different approaches are in practice to reclaim soil salinity for the remediation of the saline environment. At last, it's suggested that for the invention of at least one economically approachable and well-developed technique, the world needs more and more research on this scenario.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data present in this review that support the findings of this study are openly available.

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Figure 1: Impact of abiotic stresses on plant yield and quality (Alkharabsheh *et al.* 2021)

Figure 2: Represents the comparison of maize root growth in non-saline and saline soil

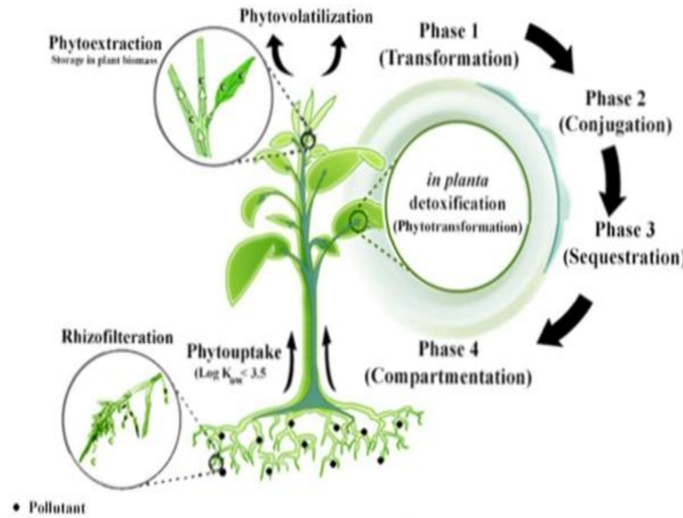

Figure 3: Green Liver model which represents plant response to xenobiotic compounds detailing plant uptake, transformation and degradation of contaminants in the plant (OVAM, 2019)

Table 1. Effects of salinity levels on crop yield

Salinity stress	**Salinity level (dS/m)**	**Effects on crop yield**
Non-Saline	<2	Negligible
Slightly-Saline	2-4	only sensitive crop
Medium-Saline	4-8	many crop
Highly-Saline	8-16	All crops except salt tolerant
Very Highly-Saline	>16	All crops except highly salt tolerant

Table 2. Beneficial effects of halotolerant microorganisms on plants' growth under saline conditions

Plants	Microorganisms	Beneficial effects	References
Zea mays	*Geobacillus sp.*	Photosynthetic and proline content increase	Mahdi *et al.*, 2020
Triticum turgidum L.	*Pseudomonas putida*	Seed germination increases	Adhikari et al., 2020
Brassica juncea L.	*Trichoderma harzianum*	Proline and pigment increased	Mahmood and Kataoka 2018

Table 3. Practices of phytoremediation for saline-sodic soil and phytoremediation species

Countries	Effected soils	Plant species	References
Pakistan	Saline, sodic, and saline-sodic soils	Forage crops, such as Kallar grass	Nadeem et al. (2017)
India	Sodic soils	Forage crops, such as Kallar grass and Rhodes grass.	Dagar et al. (2014)
India	Saline soil	Forage crops, such as Kallar grass, Sporobolus, Panicum spp., Atriplex spp.	Dagar et al. (2014)
Not specified	Sodic and saline-sodic soils	Forage crops, such as Bermuda grass, Kallar grass, river hemp, and sesbania	Qadir et al. (2007)

Table 4. Advances in remediation and their benefits to plants

Plant	Bacteria	Benefits	Reference
Cicer arietinum L. **(chick pea)**	*Mesorhizobium ciceri* G-55(salt tolerant)	Transferred with acids gene encoding ACC deaminase. Bacteria produced higher nodulation in chickpea.	(Brigido *et al*., 2013)
Oryza sativa L (Rice).	Bacillus tequilensis 10b (UPMRB9)	A high amount of N and Ca is accumulated in rice plants under salinity conditions due to strain. UPMRB9 improved peroxidase, soluble sugar concentration, and osmoprotectant.	(Shultana *et al.*, 2021)