Chapter

Interactive Effect of Organic and Inorganic Amendments along with Plant Growth Promoting Rhizobacteria on Ameliorating Salinity Stress in *Maize*

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Abstract

Saline soil is one of the common environmental issues that negatively affects the soil quality of agricultural lands. It reduces the plant growth and productivity worldwide. Soil Salinity and sodicity affecting land about 1128 million hectares globally determined by recent researches. The most important salt-sensitive cereal crops in the world are Maize (*Zea mays* L.) For food security, its need of hour to securing attainable production of maize crop in the salt affected soils. To reduce negative impacts of saline soil on plant growth, sustainable approaches such as organic amendments like press mud and inorganic amendments like silicon can be applied. For increasing crop productivity, plant growth promoting rhizobacteria (PGPR) which are salt-tolerant in saline agriculture can also be applied. In this book chapter interactive effect of different organic and inorganic amendments and plant growth-promoting rhizobacteria to reduce salinity stress on maize has been discussed.

Keywords: Salinity stress, Maize, Food security, Organic amendments, Inorganic amendments

1. Introduction

In the Arid and semi-arid areas salt affected soil poses immense threats to the agriculture industry worldwide [1]. Researchers have reported that about 1128 million ha of land is affected by salinity and sodicity globally [2]. Soil salinization at global level has caused food insecurity in several countries during last decade. In Pakistan approximately 6.8 million hectares of land is affected by salinity [3]. Saline soil is characterized by the presence of high level of sodium and its chlorides and sulphates [4]. Soil having 4 dS m^{-1} or more electrical conductivity of the saturation soil paste is considered as salt affected soil [5–7]. Due to high concentrations of Na^+ and Cl^- in the plant, Sodium chloride can reduce crop productivity by making the roots water uptake more difficult that can cause plant toxicity [8]. Research studies proved that approximately 20% of the world's cultivated land is affected by salinity [9].

Due to inappropriate management of irrigation and drainage, soil salinity is gradually increasing in irrigated lands [10]. Global warming as an environmental issue has greatly affected arid regions of the world that are at highest risk of soil salinization. Salt redistribution in the soil profile is due to climatic factor such as precipitation. Agricultural productivity is affected when salt is added by wind to coastal agricultural lands [11]. Soil Biodiversity and microbial activity is affected by the high salt concentration [12].

Under saline soil plant growth is negatively affected by osmotic effects and hormonal imbalance. It also causes nutritional disorder and specific ion toxicity [13]. The adverse effects of saline soil on plants include: (1) Osmotic potential is decreases due to excessive soluble salts in the soil solutions. It also causes physiological drought by decreasing plants ability to absorb water (2) toxicity due to salt ions inside the plant cells. The Growth inhibition is caused by sodium and chloride ions as sodium ions are retained in the roots and stems and only chloride ions become concentrated in the shoot in some plants which is causing negative affects to the plants [14, 15]. (3) Secondary stresses which is mainly caused by osmotic and ionic pressure. It includes high concentration of toxic compounds such as ROS and nutrient imbalance in plants. Sodium ions compete with potassium ions under saline condition and causing reproductive disorders by calcium ions in the cell membrane [16, 17]. The maize (*Zea mays* L). is a major food crop in the world food. The productivity of maize crop is declined as it moderately salt-sensitive plant [18].

In this scenario, it is the need of time that agronomists and environmentalists should develop eco-friendly, cost effective and sustainable methods to reclaim saline soils [19]. Currently, various physico-chemical processes are in practice for the reclamation of saline soils. To some extent these methods are unsustainable and inefficient at high salt concentration [20]. The traditional breeding and biotechnological methods for the production of salinity-tolerant crops is a time-consuming process. By using chemical neutralizers and sustainable approaches sustainable crop yield in saline soils must be secured. It can also be secured by using salt-tolerant varieties or amelioration methods.

For plant growth and development, microorganisms play an important role under different environmental conditions [21, 22]. For enhancing crop productivity in saline soil, the application of plant growth-promoting rhizobacteria has become sustainable approach [23, 24]. Inoculation with PGPR leads towards abiotic stress regulation which can cause systemic tolerance directly or indirectly [25]. Many PGPR have been applied for their positive role in improving plant-water relations and for ion homeostasis. It is also used for photosynthetic efficiency in plants under salt stress. Plants can effectively protect from many stresses by PGPR that produce IAA and ACC deaminase. IAA accumulation increase transcription of ACC synthase genes. It is resulted an increases ACC concentration that can lead to the production of ethylene. Excess ACC are broken by PGPR that produce ACC deaminase. It also decreases plant ethylene levels under harsh environmental conditions. It permits IAA to encourage the growth of the plants [26].

Bacteria secrete exopolysaccharides which can bind soil particles into aggregates. These are helpful in regulating soil structures. It also increases water holding as well as cation exchange capacity of soil [27]. An enclosed matrix of microcolonies is formed by EPS which provide protection against environmental changings. It also leads towards water as well as nutrient retention and epiphytic colonization [28]. The exopolysaccharide secretion by PGPR binds sodium ions and reduces its uptake in plants which is determined by researches studies [29].

In saline soil a diversity of salt-tolerant PGPR such as *Azospirillum, Burkholderia, Rhizobium*, *Pseudomonas*, *Acetobacter* and *Bacillus* have been applied. These are also tested for promoting plant growth under salt stress [30, 31]. Thus, it has been demonstrating by different researches that use of PGPR is a beneficial approach to increase plant performance in saline soil [32, 33]. The physiological drought is caused by salt in soil environment which reduces the ability of plants to remove water. Many biotic and physical stresses on plants can be reduced by application of Si fertilizer which can change the negative effects of saline soil [34, 35]. By improving sodium ions and potassium ions homeostasis, silicon may increase salinity tolerance in plants. It also improves nutritional status and photosynthetic efficiency of plants under stress conditions [36–38]. Many laboratory and greenhouse experiments have determined that under saline conditions, Si reduced the uptake of sodium ions and chloride ions [39, 40]. The use of organic matter increases the physico-chemical and biological properties of salt-affected soils [41]. Organic matter also plays an important role by improving roots to grow more uniformly. The soil CO_2 concentration is increased by decaying organic matter. It also releases H^+ and enhances $CaCO_3$ dissolution. It can release more calcium for sodium exchange [42] Application of press mud is very effective in reclaiming saline sodic soils [43, 44].

2. Impacts of soil salinity

2.1 Impact of soil salinity on plant growth and development

Saline soil affects plant growth, development and process of photosynthesis. It also affects protein synthesis and lipid metabolism [45]. Osmotic stress reduces photosynthetic efficiency which is resulted in partial closure of stomata [46]. The nutrient imbalance and membrane destabilization are caused by soil salinity [47]. The cell growth and development are decreased in plants in responses to osmotic stress. It resulted in decreased leaf area and chlorophyll content [48].

The nutritional imbalances are also caused by decrease in the uptake of calcium ions and potassium ions in leaves and an increase in the uptake of sodium ions. In some cases, there is a requirement of low sodium ions and high potassium ions or calcium ions are required for optimum function, but increased sodium ions resulted in metabolic disturbances. Cell swelling in plants is caused by accumulation of sodium and chloride which can affect plant enzymes. It can also result in physiological changes and reduced energy production [49]. The photosynthetic function is disturbed by nitrate reductase activity due to chloride ions [50]. There are competitive interactions with nutrient ions for binding sites. It can also affect transfer of protein in root cells under excessive sodium and chloride ions in rhizosphere. It also affects processes like movement of material, deposition, and partitioning within plants [51]. Salts can increase in intercellular spaces resulted in cell dehydration [52]. Oxidative stress increases due to the accumulation of reactive oxygen species which has negative impact on cell membranes, proteins, enzymes, and nucleic acids [53] Both antioxidant enzymes and non-enzymatic antioxidants are produced by plants to protect against oxidative stress [54].

2.2 Impacts of soil salinity on rhizosphere microbial diversity

Microbial biomass is an important parameter as it functions as an agent transformation and plays its role as the recycling of the organic matter by providing soil nutrients. In the first few centimeters of the soil surface, there are microbial biomass and organic matter. Microbiological activity is affected by the salinization process [55]. Microbial diversity, functions, and compositions are negatively affected by salinity [56]. Total bacteria and actinobacteria are reduced by a 5% increase in salinity. The attachment of *Azospirillum brasilense* to maize roots was observed to reduce due to salinity [57]. Due to increase salinity in the rhizosphere, the plant root secretion and organic matter decomposition by microorganisms are adversely affected [58].

3. Application of organic amendments to agricultural crops to mitigate salinity effects

3.1 Organic matter

There is an excess of salts in water which is used for irrigation purposes. It can reduce the crop yield due to its increased salt concentration [59]. Soil electrical conductivity is being increased due to the continuous increase of salts in it [60]. Water which is used for irrigation having excess salts in it resulted in negative impacts on plant physiology, soil water plant relationships, and limits the production of crops [61]. By application of organic manure in soil, the toxicity of salts can be minimized, and soil properties can be improved as cost-effective approaches [62].

There are agricultural practices that are used for the management of salt-affected soil [63]. Addition of organic martial is beneficial as a fertilizer which can modify and improve the soil characteristic. For recovery of saline soil, organic amendments like organic manure and compost are being tested as efficient methods [64]. Application of organic matter for the reclamation of sandy soil is an effective method to improve the physical properties of soil [65]. Researchers determined that poultry manure, farmyard manure (FYM), crop residues as compost are being used for the addition of nutrients in the soil. It is beneficial for improving plants' health. It can also modify physiochemical properties of plants [66]. Farmyard manure is the most commonly and easily available source of organic matter. There are different factors which can affect the efficiency of farmyard manure such as nature of feed consumed by the animal, type of animal and waste management methods [67].

3.2 Biochar

There are different long-term and short-term methods for reclamation of salt-affected soil, but short-term management approaches are useful as a management strategy that are cost effective and high-income generating methods [68]. The biochar is an effective method for organic amendment of salt-affected soil that results in

- Soil physicochemical and biological properties are improved
- Stomatal conductance and phytohormones can be regulated
- Reduction in oxidative stress
- Increase in mineral nutrient uptake
- Effects on plant growth, photosynthesis and biomass
- Na ion toxicity in plants is reduced

4. Application of inorganic amendments to agricultural crops to mitigate salinity effects

4.1 Exogenous application of sulfur

Salt affected soil has many salts in it and each salt has a differential contribution to salt stress. There are different salts such as Na_2SO4, NaCl, Na2CO3, CaSO4, MgCl2, KCl but the most important of these is NaCl [69–73]. For the regulation of cell metabolism and hormone signaling pathway, Sulfur plays a very important role. For regulating seed germination its acts as a biochemical agent [74, 75]. For the synthesis of protein, chlorophyll, vitamins, and glutathione which are helpful to tolerate various stresses, sulfur plays a very important role [76]. Sulfur compounds are also present in many amino acids and their composition changes by the application of sulfur [77]. To improve plant growth by improving its cellular functions especially in saline soil, the addition of sulfur is beneficial [78]. Different approaches are being applied to mitigate the deleterious effects of salinity on health of plants. The exogenous application of inorganic salts and osmo-protectants are cost efficient approach to reduce the negative effects of salt stress on plant growth [79, 80].

4.2 Use of silicon nutrition to alleviate the salt stress in maize

In contrast to Na^+ and Cl^- toxicity, silicon (Si) has ameliorative features. It can help plants to grow on saline soil. For industrialized counties, it can prove cost-effective. Under biotic stress, silicon can improve plant growth also reduces radiation effects on it. It is helpful in reducing water loss up to 30% [81]. The exogenous application of Si for different salt-tolerant plant species has been reported [82, 83]. Under saline environment, Si uptake by plats increases root activity and inhibits transpiration. But in the plasma membrane, it increases the activity of ATPase and PPase. This can result in decrease in Na uptake and an increase in K uptake [84, 85].

4.2.1 Silicon-mediated mechanisms underlying increased crops tolerance to salinity

Si application can directly influence growth of plants by diminishing the transport of Na^+ ions while indirectly activating physiological processes under saline conditions.

4.2.1.1 Reduced Na^+ uptake by plant roots due to Si application

Due to high concentration of Cl^- and Na^+ and low concentration of K^+ and Ca^{+2} in the saline environment, Na^+/K^+ ratio vary in plants [84]. Due to elevated level of Na^+ and overproduction of ROS, plant metabolism is being changed [85] Research studies demonstrated that Si can reduce ion toxicity which is resulted from the saline condition. It is also helpful in increasing K^+ and decreasing Na^+ uptake [86]. Thus, research studies determined that Si application resulted in reduced Na^+ buildup in the roots [86]. Si as phytolith, accumulates different parts of plant bodies. Si deposits underneath cell walls of roots to bind the Na^+ and reduces Na^+ toxicity by decreasing the Na^+ transport in upper regions and increasing the K^+ uptake.

4.2.1.2 Stimulation of antioxidant defense system in crops

Under the saline conditions, studies have determined the enhanced production of antioxidant due to the application of Si [87]. Effects of Si on the antioxidants depend upon different factors like the severity of saline stress, time, plant species, and the concentration of Si. Thus, studies determined that application of Si can regulate antioxidant defense system by reducing salinity effects. This also resulted in decrease lipid peroxidation and regulate membrane integrity. It also can decrease permeability of plasma membrane. The research studies determine that non-Si-treated and Si-treated plants show different responses under saline conditions. Application of Si plays a protective role to improve antioxidant activity.

5. Role of PGPRs in alleviation of salinity stress in maize crop

In the semi-arid environment, salinity pose negative effects on the growth and production of various crops. It also affects aggregate stability of soil. Soil structure stability has important for improvement of soil properties. The soil microbial communities such as free-living or symbiotic organisms play an immense role to improve soil structure. It is proved that the activities which microbes performed to soil aggregate stability are very advantageous [88]. It can efficient solution for saline soil and make it fit for agricultural practices. PGPRs can help in inducing plant tolerance to various abiotic stresses including salt stress. In saline environments, PGPR-crop interactions improved the plant growth. It can also promote plant survival in adverse conditions [89]. PGPR promote the growth and development of plants by providing nitrogen, phytohormones soluble phosphates, and iron [90]. The plant is being protected against various soil-borne diseases, and it is known that most of these diseases are caused by pathogenic fungi [91].

5.1 Various attributes of PGPsRs in mitigating negative effects of salt stress in maize crop

5.1.1 Enhanced root proliferation and plant vigor

PGPRs can promote the growth of the plants by means of PGPRs which colonize the rhizosphere [92]. The co-inoculation of seeds of different PGPR species is a beneficial strategy to remediate salt-stressed soil. This approach has improved the plant tolerance towards abiotic stresses and the structure of root hairs.

5.1.2 Phytohormones produced by bacteria

The physiological response in plants is increased by phytohormones produced by microbes in root zone. Production of indoleacetic acid and gibberellins promote the root length. It also increases number of tips, surface area of roots and uptake of nutrients thus promoting the plant vigor exposed to saline conditions [93–96]. Indole acetic acid production is a common characteristic of PGPR. This bacterium is observed to reduce salinity stress in plants.

5.1.3 Role of PGPR as a sink for 1-aminocyclopropane-1-carboxylate (ACC)

Increase in ACC levels can result in higher ethylene production under saline environment. It can also increase plant injuries [97, 98]. Cobalt ions and amino ethoxy vinyle glycine as chemical inhibitors of ethylene synthesis is often used to control salinity problems. These chemicals are expensive and have harmful effects on the environment. PGPR play a role of sink for ACC which can be hydrolyzed to generate a-ketobutyrate and ammonia to reduce the ethylene production.

5.1.4 PGPR-mediated ion homeostasis

Plants inoculated with PGPR have showed high concentration of K^+ which led to high Na^+/K^+ ratio and ultimately improved tolerance towards salt stress [99–101]. Salinity can damage the cell-membrane in plants which can enhance its permeability and electrolyte leakage. In maize, Lower the electrolyte leakage has been determined the inoculation with Rhizobium [102–104].

5.1.5 Accumulation of osmolytes

The functioning of photosynthetic structures and maintaining water homeostasis are essential for reducing salinity impact on plants. Excessive production of various compatible organic solutes (such as glycine betaine and proline) has been observed as stress responses in plants [105]. Accumulation of proline is a physiological response of plants to saline conditions [106]. It also maintains high leaf water potential and protects the plants from negative effects of oxidative stress. Researchers have determined that PGPRs contribute to accumulation of osmolytes to increase plant tolerance towards stress.

5.1.6 Antioxidative enzymes

Reactive oxygen species (ROS) damage the nucleic acids, proteins and lipids. Limited photosynthetic activity under salinity promotes the excessive production of ROS [107]. Antioxidants have been found to greatly reduce the oxidative damage. Under saline conditions, the activities of the enzymatic antioxidants such as guaicol peroxidase, catalase and superoxide dismutase increased [108]. Researchers determined that the application of PGPR caused a significant increase in polyphenol oxidase, superoxide dismutase and other enzymes involved in plant defense system. It also increases in enzymes such as peroxidase, phenyl alanine ammonia-lyase, catalase, phenolics and lipoxygenase [109–111]. These PGPR-stimulated enzymes are playing important role in removing hydrogen peroxide from stressed roots [112].

5.1.7 Ameliorating effects of bacterial extracellular polymeric substances (EPS)

Researchers determined that inoculation with EPS-producing PGPR have significantly increased the volume of soil macropores, rhizospheric soil aggregation, improved fertilizer as well as water availability. This approach can help plants to survive in salt-stressed soils. Different studies have shown positive effects of EPS-producing PGPR on the rhizospheric soil aggregation [113]. As bacterial EPS can sequester the cations, there may be an opportunity to eliminate the salinity stress by increasing the EPS-producing PGPR strains [114].

5.1.8 Enhancement of plant nutrient uptake

It is obvious that PGPR can regulate the availability of plant nutrients. So, employing PGPR can cut down the use of chemical fertilizers. Various PGPR strains are involved in solubilizing the inorganic phosphate and mineralization of organic phosphate, thus providing nutrients to plants [115]. However, the former activity of PGPR is the key role of PGPR in providing nutrients to plants.

5.1.9 PGPR-mediated disease suppression

Many rhizobacteria are known to produce antifungal metabolites like phenazines, HCN, pyrrolnitrin, tensin, pyoluteorin, 2,4-diacetylphloroglucinol, and viscosinamide [116]. However, various PGPR strains can control the pathogen of plants grown under salt stress.

6. Interactive techniques to ameliorate salinity stress in maize

6.1 Silicon and PGPR to mitigate salt stress in maize

An environment-friendly and cost-effective approach for lessening salinity in crop plants is the co-application of silicon and PGPR [117]. Different studies have shown that by improving photosynthetic efficiency, and scavenging enzyme activity soil salinity tolerance can be enhanced. It also determined that this approach can improve the plant tolerance towards salinity, ROS and Na^+/K^+ ratio [118]. PGPR promote the growth of plants via synthesis of phytohormones, exopolysaccharides, volatile organic compounds and different other mechanisms [118]. Recently, it has been found that both Si and PGPR can enhance plants tolerance to saline environment to improve growth and yield of plants [118].

6.2 Combined effects of biochar and plant growth-promoting bacterial endophytes on alleviating salt stress in maize

Employing the salt tolerant PGPR to enhance crop productivity has been a sustainable and efficient method [119–122]. Researchers have documented that PGPR produced the exopolysaccharide (EPSs) that prevent the uptake of Na + ions by sequestering these ions [123, 124]. Studies demonstrated that few PGPR have an important enzyme, ACC- deaminase, which can reduce ethylene production by metabolizing ACC into ammonia. ACC is the precursor of ethylene and a-ketobutyrate [125–127]. Unlike PGPR, plant growth-promoting bacterial endophytes colonize the internal tissues of plants without causing any harm to the plants [128]. It can lead to several physiological modifications that contribute to plant growth and development [129–131]. These, plant growth-promoting bacterial endophytes may promote plant growth by adopting the similar mechanisms as observed in PGPR [132]. Thus, it is proved that plant growth-promoting bacterial endophytes are more effective in promoting plant growth even under severe stresses as compared to PGPR. Different researchers have demonstrated that for reducing soil salinity addition of biochar along with endophytic bacteria is an efficient and environment friendly approach [133].

For enhancing crop growth and yield, use of biochar is cost effective and eco-friendly option to boost water and nutrient-holding capacity of soil [134–137]. Application of biochar has positive effects on physicochemical properties of soil. Moreover, Biochar can also improve a variety of soil microbes by providing them a favorable habitat and nourishment [138]. Thus, it is an excellent solution for recycling organic waste and solution to environmental pollution.

There are three important mechanisms underlying biochar-mediated reduction of salt stress in plants. These include:

a. High adsorption of Na^+ on biochar resulting in reduced availability of Na^+ in soil solution

b. Regulation of ions concentration in soil solution by liberating mineral nutrients

c. Dilution of soil solution via increasing available moisture contents of soil to reduce the osmotic stress [139].

7. Conclusion

Reclamation of saline soils is mainly achieved by employing various physicochemical processes. However, these processes are not sustainable and considered inefficient in the case of high salt concentration. PGPR contain a vital enzyme, 1-aminocyclopropane-1-carboxylate deaminase that can decrease salinity induced ethylene production. Silicon and elemental sulfur can also be applied to reduce the negative effects of soil salinity on plants. The organic matter such as press mud usually contains about 70% lime, 15–20% organic matter and 23% sugar. This organic matter is highly soluble and readily available to the microbial activity and soil. Due to microbial activity more carbon dioxide is produced that may increase the solubility of lime and hence reclaim the saline soils. Hence, the combine application of organic amendments (like press mud), inorganic amendments (like silicon and elemental sulfur) and PGPR can ameliorate the saline soil in an environmentally sustainable way.

Conflicts of interest

The authors declare no conflict of interest.

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