R-2648
[1-7]

REVIEW ARTICLE Agricultural Re

Promoting Sustainable Agriculture: Approaches for Mitigating Soil Salinity Challenges: A Review

Sarita[1], Bhupnesh[1], Vinod Goyal[1]

10.18805/ag.R-2648

ABSTRACT

Soil salinity is a major abiotic stress which limits the agricultural productivity throughout the world. Anthropogenic strategies play a vital role in mitigating soil salinity and restoring soil health. These strategies encompass physical, chemical and biological processes, each targeting different aspects of soil salinity management. Physical processes involve the manipulation of soil and water properties to minimize salt accumulation. Improved irrigation techniques, such as drip irrigation and sprinkler systems, optimize water distribution and minimize salt buildup. Efficient drainage systems prevent waterlogging and facilitate salt leaching. Chemical processes focus on modifying the soil environment through amendments, such as gypsum and organic matter additions, to enhance soil structure, nutrient availability and salt displacement. These processes improve soil quality and salt management. Biological processes exploit the capabilities of halophytes, salt-tolerant plant species, to reduce soil salinity by accumulating salts in their tissues. Microbial inoculants or biofertilizers containing beneficial microorganisms enhance nutrient cycling, soil structure and plant tolerance to salinity. The integration of physical, chemical and biological processes offers a comprehensive approach to soil salinity mitigation. By combining these strategies, researchers and practitioners can develop tailored management plans that address site-specific conditions and crop requirements. Successful implementation of anthropogenic strategies can lead to sustainable solutions for soil salinity, improving agricultural productivity and promoting the long-term health of soil ecosystems. This comprehensive review provides insights into the latest research trends and advancements in anthropogenic strategies for mitigating soil salinity, contributing to the development of effective and sustainable approaches for soil salinity management.

Key words: Agricultural productivity, Biological processes, Chemical processes, Physical processes, Soil salinity.

Soil salinity is a major abiotic stress factor that significantly affects agricultural productivity and poses a global challenge to sustainable food production. The FAO reports that soil salinization renders up to 1.5 million hectares of farmland unproductive each year. Furthermore, it decreases the production potential of up to 46 million hectares of land worldwide (FAO, 2021). India experiences an annual loss of approximately 16.84 million tons of farm produce due to soil salinization (Kumar and Sharma, 2020). It is characterized by the excessive accumulation of salts in the soil, particularly sodium chloride and other soluble salts, which can hinder plant growth and development. It is characterized by the excessive accumulation of salts in the soil, particularly sodium chloride, and other soluble salts, which can hinder plant growth and development. Soil salinity is primarily caused by natural processes, such as geological formations, weathering of rocks and seawater intrusion, but anthropogenic activities have also contributed significantly to the problem. Anthropogenic factors, including improper irrigation practices, excessive use of fertilizers and inadequate drainage systems, have accelerated the onset and severity of soil salinity as shown in Fig 1. As a consequence, there is an urgent need to develop effective strategies to mitigate soil salinity and restore soil health to ensure agricultural sustainability. Mitigating soil salinity requires a multidimensional approach that integrates various anthropogenic strategies aimed at reducing salt accumulation, improving soil structure and promoting plant tolerance to salinity stress. These strategies encompass a range of management practices, technological advancements and policy interventions.

One of the key anthropogenic strategies is the implementation of improved irrigation techniques as shown in Fig 1. For instance, adopting precision irrigation methods, such as drip irrigation or sprinkler systems, can minimize water wastage and the leaching of salts beyond the root zone (Maas and Hoffman, 1977; Zeng *et al*., 2021). This approach helps maintain a more balanced soil moisture content and reduces the risk of salt buildup. Additionally, investigations into the design and implementation of efficient drainage systems have provided insights into their role in preventing waterlogging and

[1]Department of Botany and Plant Physiology, CCS Haryana Agricultural University, Hisar-125 004, Haryana, India.

Corresponding Author: Sarita, Department of Botany and Plant Physiology, CCS Haryana Agricultural University, Hisar-125 004, Haryana, India. Email: jakhar.sarita.1995@gmail.com

How to cite this article: Sarita, Bhupnesh and Goyal, V. (2024). Promoting Sustainable Agriculture: Approaches for Mitigating Soil Salinity Challenges: A Review. Agricultural Reviews. DOI: 10.18805/ag.R-2648

Submitted: 06-07-2023 **Accepted:** 04-01-2024 **Online:14-02-2024**

facilitating salt leaching (Rhoades *et al*., 1992; Alzubaidi *et al*., 2022).

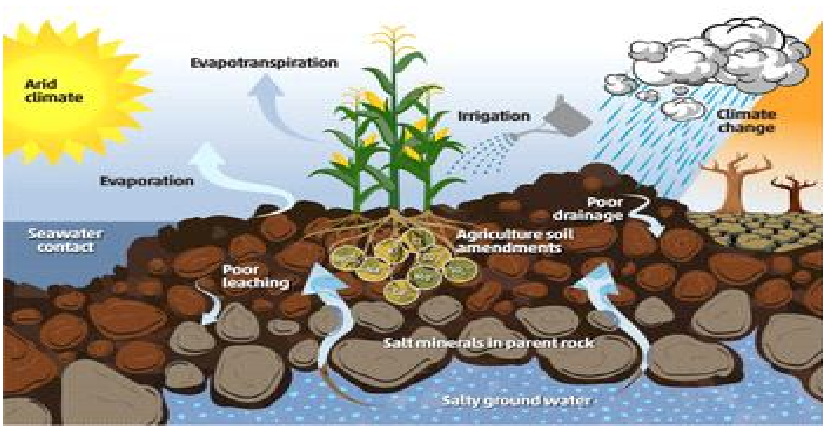
In addition, effective soil management practices play a vital role in mitigating soil salinity. Implementing proper soil nutrient management plans, including balanced fertilization and organic matter additions, can enhance soil fertility and improve nutrient availability for plants (Munns and Tester, 2008; Hussain *et al*., 2021). Moreover, incorporating suitable soil amendments such as gypsum or organic materials, can aid in the leaching of excessive salts and improve soil structure, thereby facilitating better root growth and nutrient uptake.

Another important anthropogenic strategy is the development and utilization of salt-tolerant crop varieties through breeding and genetic engineering approaches (Munns and Gilliham, 2015; Flowers *et al*., 2020). Selective breeding programs aim to incorporate genes responsible for salt tolerance from wild relatives into commercially important crop species, enhancing their ability to withstand salinity stress. Genetic engineering techniques offer additional opportunities to introduce novel genes or modify existing genes to confer salt tolerance traits to crops.

Furthermore, effective land and water management practices can contribute to mitigating soil salinity. Implementing appropriate land-use planning strategies, such as afforestation, agroforestry, or integrated farming systems, can help stabilize soil structure, improve water infiltration and reduce the risk of salt accumulation (Kumar *et al*., 2019; Islam *et al*., 2021). Furthermore, regulating water usage and promoting sustainable irrigation practices through policy interventions can minimize the impact of anthropogenic activities on soil salinity (Sharma *et al*., 2020; Wei *et al*., 2021).

Anthropogenic strategies for mitigating soil salinity

Some anthropogenic strategies are used to reduce soil salinity. They may be physical, chemical, or biological as shown in Fig 2.



https://www.fao.org/3/cb7247en/cb7247en.pdf

Fig 1: Factors influencing salt accumulation in the soil.

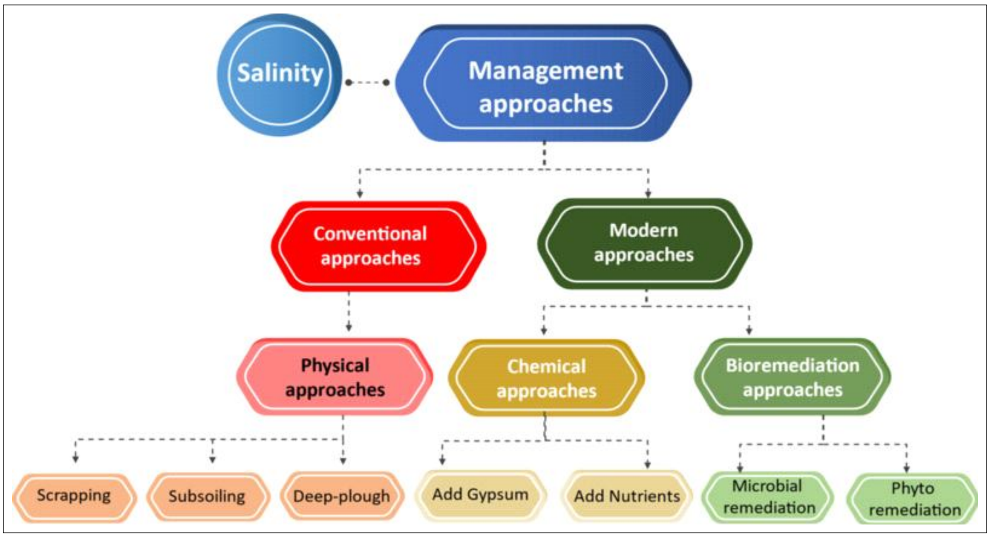


Fig 2: The conventional and modern approaches for soil salinity management.

Physical

Leaching, a commonly employed method for remediating salt accumulation in soils, involves the application of large volumes of good-quality to wash away soluble salts (Ravindran *et al*., 2007). This approach is considered highly effective, particularly in regions with a low water table and abundant good-quality resources. However, areas affected by soil salinization are often arid or semi-arid, resulting in limited access to water.

Deep tillage is another physical decontamination technique that can be employed to address soil salinity. This method involves mixing the surface soil, which tends to have high salt content, with deeper soil layers. The mixing process effectively dilutes the salt concentration in the upper soil profile (Provin and Pitt, 2017). Although deep tillage can promote improved plant growth, it is associated with significant disruptions and increased erosion rates. Moreover, deep tilling may enhance evaporation rates, exacerbating the salt problem. Deep tilling can exacerbate soil salinity by exposing deeper saline layers, disrupting capillary rise and increasing the evaporation of water within the soil, ultimately leading to higher salt concentrations near the surface where plants grow (Cuevas *et al*., 2019).

The management of soil salinity can be achieved through the implementation of soil-improving cropping systems (SICS) (Cuevas *et al*., 2019). These systems not only incorporate established techniques like leaching with high-quality water but also involve the use of salt-resistant plant species to enhance overall soil fertility. While SICS is primarily applied in agricultural contexts, plant-based remediation approaches utilizing halophytes can be employed in various settings to effectively manage saline soils.

Chemical use strategies

To improve soil quality, the application of chemical amendments is an additional option. One such amendment is gypsum ($CaSO_4$), which can enhance calcium levels and improve soil structure (Gupta and Abrol, 1990). Saline soils exhibit diverse compositions and require specialized approaches, including the use of sulfur-containing compounds like gypsum, for effective management and long-term reclamation (Stamford *et al*., 2015).

Gypsum application is a prominent method used to reclaim salt-affected soils, with other related amendments including elemental sulfur, sulfuric acid (H_2SO_4), polysulfides of sulfur and hydrogen sulfite (Abdelhamid *et al*., 2013; Lastiri-Hernández *et al*., 2019; Wang *et al*., 2019). Field studies have demonstrated the effectiveness of gypsum in soil reclamation, particularly in comparison to other amendments (Lastiri-Hernández *et al*., 2019). Gypsum application to saline soils can lead to improvements in various soil properties, such as physical characteristics (bulk density, aggregate stability and water infiltration) and chemical attributes (pH, SAR, ESP, CEC, EC, nutrient availability and organic carbon) (Lastiri-Hernández *et al*., 2019; Wang *et al*., 2017; Kim *et al*., 2016). Additionally, gypsum application has been shown to increase biomass production and crop yields (Lastiri-Hernández *et al*., 2019; Wang *et al*., 2017).

Gypsum ($CaSO_4$) has several beneficial effects when applied to saline soils. One of the primary advantages is its ability to enhance soil structure. Saline soils often have poor physical characteristics, such as high bulk density and low aggregate stability, which can hinder water infiltration and root penetration. Gypsum, when applied into the soil, helps to loosen compacted layers and improve soil porosity. It promotes the formation of stable soil aggregates, creating a more favorable environment for root growth and water movement (Wang *et al*., 2017; Kim *et al*., 2016).

In addition to improving soil structure, gypsum application has a significant impact on soil chemistry. Saline soils tend to have high levels of sodium, which can negatively affect soil properties and plant growth. Gypsum contains calcium, which competes with sodium for soil exchange sites. By displacing sodium ions and increasing the calcium content, gypsum helps to reduce soil sodicity and improve the soil's ability to retain essential nutrients (Kim *et al*., 2016; Alcívar *et al*., 2018). This leads to a more favorable soil pH, reduces the sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) and increases the cation exchange capacity (CEC) of the soil (Wang *et al*., 2017).

The application of gypsum enhances nutrient availability, including phosphorus and promotes a balanced concentration of electrolytes in the soil solution (Kim *et al*., 2016; Alcívar *et al*., 2018). Furthermore, gypsum treatment not only modifies the physical and chemical properties of the soil but also stimulates microbial activity, biomass and respiration (Alcívar *et al*., 2018).

Apart from its effects on soil physical and chemical properties, gypsum also plays a crucial role in stimulating soil microbial activity. Microorganisms are essential for nutrient cycling, organic matter decomposition and overall soil health. Gypsum application has been shown to enhance soil microbial biomass, activity and respiration rates (Alcívar *et al*., 2018). This increased microbial activity can lead to improved nutrient mineralization and organic matter decomposition, facilitating nutrient cycling and promoting a more favorable soil environment for plant growth.

Biological

Amending salt-affected soils requires considering the type of salinity present and the availability of suitable soil amendments. Two effective options for improving the biological, physical and chemical aspects of saline soils for food production are the application of $CaSO_4.2H_2O$ (gypsum) and bio-organic amendments.

Bio-organic amendments involve the use of beneficial bacteria and organic nutrients to enhance crop yield. These amendments contribute to the increase in soil organic matter, important nutrients (particularly nitrogen and phosphorus), water availability, soil structure and microbial activity (Bello *et al*., 2021). Beneficial microbes include plant growth-promoting microorganisms, arbuscular mycorrhizal fungi, cellulose-decomposing bacteria, phosphorus-solubilizing bacteria and nitrogen-fixing bacteria. By harnessing the ecological survival traits of these microbes, such as salinity tolerance and the production of growth-stimulating hormones and compatible solutes like glycine betaine, crop tolerance to salt-affected soil conditions can be enhanced (Murphy *et al*., 2018; Shrivastava *et al*., 2015; Mbarki *et al*., 2017).

Plant root-colonizing microorganisms, such as fungi and bacteria, form symbiotic partnerships with plants to impart salinity tolerance. These partnerships facilitate better root system growth, leading to improved nutrient and water uptake and the balance of sodium ions (Na^+) in the rhizosphere. For example, the dual inoculation of arbuscular mycorrhizal fungus *Rhizophagus intraradices* and plant growth-promoting bacteria *Massilia sp.* RK4 has been shown to increase nutrient accumulation, arbuscular mycorrhizal colonization and leaf proline synthesis (Krishnamoorthy *et al*., 2016). Soil microbes also play a vital role in nutrient cycling through processes such as mineralization and immobilization, which enhance soil nutrient availability, aeration and organic matter content (Xu *et al*., 2015). Specific microbial species like *Pseudomonas stutzeri* and *Trichoder maharzianum* have been found to improve salt tolerance in glycophyte plants by reducing reactive oxygen species toxicity, superoxide dismutase activity and lipid peroxidation (Mbarki *et al*., 2017; Bacilio *et al*., 2016). *Trichoder maharzianum* application has been demonstrated to improve tomato yield, soil fertility and biodiversity under salinity stress (Wagner *et al*., 2016). Additionally, inoculation with *Trichoder maharzianum*has been shown to reduce sodium absorption ratio (SAR), enhance tomato fruit output and increase soil phosphorus levels (Daliakopoulos *et al*., 2019). In a 3000-ppm salty water irrigation experiment, *Azospirillum*, peanut compost and their combination (*Azospirillum*–compost) increased germanium plant growth and biomass yield with reduced Na^+ accumulation (Leithy *et al*., 2009). *Bacillus pumilus* and *Pseudomonas pseudoalcaligenes* improve rice (GJ17, a salt-sensitive cultivar) tolerance to salinity stress by reducing ROS toxicity, superoxide dismutase activity and lipid peroxidation (Jha *et al*., 2014). Other microbial mechanisms that enhance crop tolerance to salinity stress include increased 1-aminocyclopropane-1- carboxylate deaminase, nitrate reductase and nitrogenase activities, regulation of leaf water content, phosphate solubilization, higher K^+/Na^+ ratio, improved germination and growth, indole acetic acid and exopolysaccharide production and regulation of Na^+ transporter (HKT1) (Shrivastava and Kumar, 2015) (Fig 3).

In terms of organic amendments, the addition of materials such as compost, straw, manure, humic compounds and biochar to salt-affected soils has shown potential in increasing crop production. Organic soil additives undergo breakdown processes, releasing CO_2, H^+ and organic acids (Kitila *et al*., 2020). Soil microorganisms absorb CO_2 as soil organic carbon, while plant residues contribute to soil organic carbon through CO_2 fixation during photosynthesis in the rhizosphere (Ontl and Schulte, 2012). The release of H^+ from organic breakdown facilitates the solubilization of salts and carbonates and the subsequent solubilization of $CaCO_3$ in calcareous soils releases calcium ions (Ca^{2+}) for plant uptake and CO_2 for soil organic carbon. Organic acids also contribute to soil mineralization. Application of organic amendments to saline soils has been found to improve soil electrical conductivity (EC) and pH, leading to enhanced maize growth compared to untreated control (Khatun *et al*., 2019). Organic amendments help control salt distribution in the rhizosphere, reducing soil evaporation, saltwater transport and salt accumulation in the root zone (Cuevas

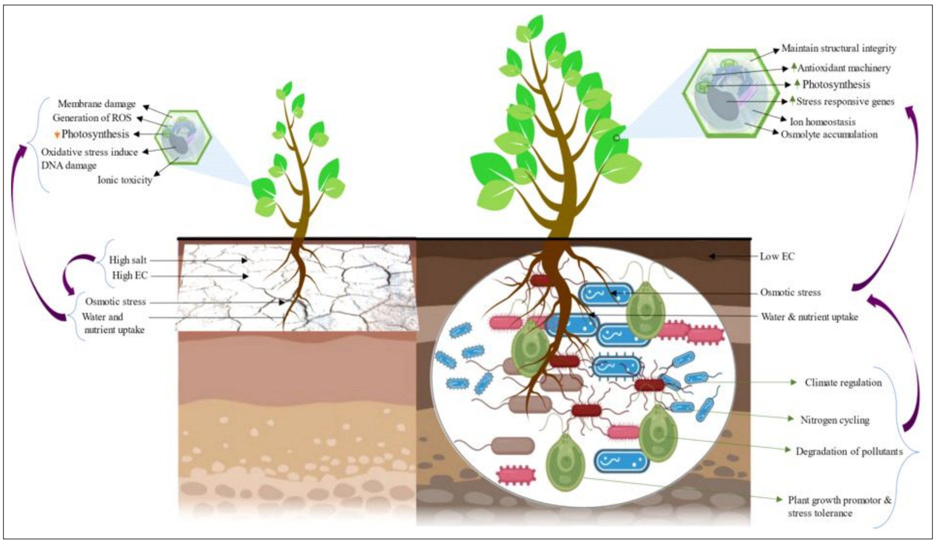


Fig 3: Role of microorganisms in mitigating soil salinity.

et al., 2019). Organic matter also chelates Ca^{2+} and Mg^{2+} in the soil solution, promoting their absorption by plants relative to Na^{+} and reducing SAR. Wheat straw application, similar to gypsum, has been shown to add Ca^{2+} and Mg^{2+} to the soil solution, making these cations more available for plant absorption (Wheaton *et al*., 2002). Additionally, the addition of organic manure to saline-irrigated soil has been found to increase the availability of nitrogen and potassium for tomato plants (Gómez *et al*., 1992).

Phytoremediation

Phytoremediation is a process used to remove, prevent the buildup of, or decompose potentially hazardous substances in the soil. It has been successfully employed for various contaminants, including metals, organic pollutants and even salt, offering a cost-effective approach (cost of treatment by using phytoremediation was found to be 5-13 times lesser than the chemical treatment (Raskin and Ensley, 2000) to soil remediation (Campos *et al*., 2008; Jesus *et al*., 2015; Mahar *et al*., 2016) as its ability to utilize natural processes, reduce the need for costly interventions and offer a sustainable, adaptable and environmentally friendly approach to soil remediation.

When it comes to salt-affected soils, the use of halophytic plants in phyto-adaptation can be particularly beneficial. Halophytes are plant species adapted to thrive in high-salt environments. By utilizing these plants, landowners can reduce costs associated with soil remediation and minimize disturbance to the soil and the interconnected ecosystems (Jesus *et al*., 2015).

In phytoremediation applications, certain halophytes known as accumulators can be employed. These plants have the ability to accumulate and remove salt from the soil, making them effective in restoring salty and sodic soils (Jesus *et al*., 2015). However, the benefits of halophytic plants extend beyond salt removal. For instance, studies conducted with *Leptochloa fusca* L., a halophytic grass, have shown that it enhances salt leaching, leading to a reduction in soil salinity and sodicity. *Leptochloa fusca*, enhances salt leaching by absorbing, excreting and transporting salts from the soil to its leaves, where they can be washed away. This natural process, along with improved soil structure and microbial activity, collectively leads to a reduction in soil salinity and sodicity. The grass achieves this by releasing carbon dioxide from its roots, which contributes to a decrease in soil pH and by dissolving calcium carbonate (Akhter *et al*., 2003). By improving soil conditions through these mechanisms, halophytes can create a more favorable environment for plant growth. Furthermore, halophytes, like other plant species, contribute to an increase in organic matter content in the soil. This organic matter helps improve soil structure, water retention and nutrient availability, ultimately enhancing soil quality. Additionally, the incorporation of organic matter by halophytic plants aids in the sequestration of carbon in the soil, contributing to carbon storage and mitigating climate change (Jesus *et al*., 2015).

CONCLUSION

Various strategies have emerged as crucial tools for mitigating soil salinity and ensuring sustainable agriculture. Through the integration of physical, chemical and biological processes, these strategies offer a comprehensive approach to address the complex nature of soil salinity. By manipulating soil and water properties, improving irrigation practices, implementing efficient drainage systems and utilizing soil amendments, salt-tolerant crops and beneficial microorganisms, researchers and practitioners can effectively manage soil salinity and restore soil health. Efficient drainage systems have proven valuable in preventing waterlogging and facilitating salt leaching. Additionally, the application of soil amendments, the utilization of salt-tolerant crops and the use of microbial inoculants have shown promise in improving soil fertility, nutrient availability and plant tolerance to salinity stress. It is evident that a multidimensional approach, combining physical, chemical and biological processes, is essential for successful soil salinity mitigation. By tailoring these strategies to site-specific conditions and crop requirements, agricultural productivity can be improved while minimizing negative environmental impacts. Furthermore, ongoing research and innovation in this field hold the potential to further enhance the effectiveness and sustainability of anthropogenic strategies for soil salinity management.

Conflict of interest

All authors declare no conflicts of interest related to the submitted work.

REFERENCES

Abdelhamid, M., Eldardiry, E. and Abd El-Hady, M. (2013). Ameliorate salinity effect through sulphur application and its effect on some soil and plant characters under different water quantities. Agriculture Science. 4: 39-47.

Akhter, J., Mahmood, K., Malik, K.A., Ahmed, S. and Murray, R. (2003). Amelioration of a saline sodic soil through cultivation of a salt-tolerant grass *Leptochloafusca*. Environmental Conservation. 30(2): 168-174.

Alcívar, M., Zurita-Silva, A., Sandoval, M., Muñoz, C. and Schoebitz, M. (2018). Reclamation of saline-sodic soils with combined amendments: Impact on quinoa performance and biological soil quality. Sustainability. 10(9): 3083. DOI: 10.3390/su10093083.

Alzubaidi, A.S., Sadeghi, S.H., Parsinejad, M., Peralta, R.C. and Mohanty, B.P. (2022). Evaluation of subsurface drainage systems to mitigate soil salinity. Water. 14(3): 694.

Bacilio, M., Moreno, M. and Bashan, Y. (2016). Mitigation of negative effects of progressive soil salinity gradients by application of humic acids and inoculation with *Pseudomonas stutzeri* in a salt-tolerant and a salt-susceptible pepper. Applied Soil Ecology. 107: 394-404.

Bello, S.K. and Yusuf, A.A. (2021). Phosphorus influences the performance of mycorrhiza and organic manure in maize production. Journal of Plant Nutrition. 44(5): 679-691.

Campos, V.M., Merino, I., Casado, R. and Gómez, L. (2008). Phytoremediation of organic pollutants: A review. Spanish Journal of Agricultural Research. 6: 38-47. DOI: 10.5424/SJAR/200806S1-372

Cuevas, J., Daliakopoulos, I.N., del Moral, F., Hueso, J.J. and Tsanis, I.K. (2019). A review of soil-improving cropping systems for soil salinization. Agronomy. 9(6): 295. DOI: 10.3390/AGRONOMY9060295.

Daliakopoulos, I.N., Apostolakis, A., Wagner, K., Deligianni, A., Koutskoudis, D., Stamatakis, A. and Tsanis, I.K. (2019). Effectiveness of *Trichoderma harzianum* in soil and yield conservation of tomato crops under saline irrigation. Catena. 175: 144-153.

FAO, (2021). Food security and nutrition around the world: Hunger is on the rise. Rome.

Flowers, T.J., Munns, R., Colmer, T.D. and Salama, N.K. (2020). Breeding crops for improved salt tolerance: Progress and prospects. Journal of Experimental Botany. 71(2): 408-421.

Gomez, I., Navarro Pedreño, J. and Mataix, J. (1992). The influence of saline irrigation and organic waste fertilization on the mineral content (N, P, K, Na, Ca and Mg) of tomatoes. Journal of the Science of Food and Agriculture. 59(4): 483-487.

Gupta, R.K. and Abrol, I. (1990). Salt-affected soils: Their reclamation and management for crop production. Environment. 33: 566-589.

Hussain, S., Mehmood, S.S., Akram, M., Riaz, M., Mahmood, A., Ali, H. and Rizwan, M. (2021). Soil amendments for sustainable agriculture: A review. Agronomy.11(8): 1646.

Islam, M.M., Rahman, M.M., Hasanuzzaman, M., Rahman, M.S. and Haque, M.A. (2021). Afforestation approaches for sustainable land management: A review. Forests. 12(4): 460.

Jesus, J.M., Danko, A.S., Fiúza, A. and Borges, M.T. (2015). Phytoremediation of salt-affected soils: A review of processes, applicability and the impact of climate change. Environmental Science and Pollution Research. 22(9): 6511-6525.

Jha, Y. and Subramanian, R.B. (2014). PGPR regulate caspase-like activity, programmed cell death and antioxidant enzyme activity in paddy under salinity. Physiology and Molecular Biology of Plants. 20: 201-207.

Khatun, M., Shuvo, M.A.R., Salam, M.T.B.R. and Hafizur, S.M. (2019). Effect of organic amendments on soil salinity and the growth of maize (*Zea mays* L.). Plant Science Today. 6: 106-111.

Kim, H.S., Kim, K.R., Lee, S.H., Kunhikrishnan, A., Kim, W.I. and Kim, K.H. (2016). Effect of gypsum on exchangeable sodium percentage and electrical conductivity in the Daeho reclaimed tidal land soil in Korea: A field-scale study. Journal of Soils and Sediments. 18: 336-341.

Kitila, K., Chala, A. and Workina, M. (2020). Effect of gypsum and compost application in reclaiming sodic soils at small-scale irrigation farm in Bora District of East Shewa Zone, Oromia, Ethiopia. Agriways. 8: 28-44.

Krishnamoorthy, R., Kim, K., Subramanian, P., Senthilkumar, M., Anandham, R. and Sa, T. (2016). *Arbuscular mycorrhizal* fungi and associated bacteria isolated from salt-affected soil enhance the tolerance of maize to salinity in coastal reclamation soil. Agriculture, Ecosystems and Environment. 231: 233-239.

Kumar, V., Tomar, S.S., Kumar, R., Singh, A.P., Meena, R.S. and Lal, R. (2019). Agroforestry systems for enhancing soil health and farm income: An overview. Agroforestry Systems. 93(5): 1701-1719.

Lastiri-Hernández, M.A., Alvarez-Bernal, D., Bermúdez-Torres, K., Cárdenas, G.C. and Ceja-Torres, L.F. (2019). Phytodesalination of moderately saline soil combined with two inorganic amendments. Bragantia. 78: 579-586.

Leithy, S., Gaballah, M. and Goma, A. (2009). Associative impact of bio-and organic fertilizers on geranium plants grown under saline conditions. International Journal of Academic Research. 1: 17-23.

Maas, E.V. and Hoffman, G.J. (1977). Crop salt tolerance-current assessment. Journal of the Irrigation and Drainage Division. 103(2): 115-134.

Mahar, A., Wang, P., Ali, A., Awasthi, M.K., Lahori, A.H., Wang, Q. and Zhang, Z. (2016). Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: A review. Ecotoxicology and Environmental Safety. 126: 111-121.

Mbarki, S., Cerda, A., Brestic, M., Mahendra, R., Abdelly, C. and Pascual, J.A. (2017). Vineyard compost supplemented with *Trichoderma harzianum* T78 improves saline soil quality. Land Degradation and Development. 28(4): 1028-1037.

Munns, R. and Gilliham, M. (2015). Salinity tolerance of crops-what is the cost? New Phytologist. 208(3): 668-673.

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. Annual Review of Plant Biology. 59: 651-681.

Murphy, B.R., Jadwiszczak, M.J., Soldi, E. and Hodkinson, T.R. (2018). Endophytes from the crop wild relative *Hordeum secalinum* L. improve agronomic traits in unstressed and salt-stressed barley. Cogent Food and Agriculture. 4(1): 1549195. DOI: 10.1080/23311932.2018.1549195.

Ontl, T. and Schulte, L. (2012). Soil Carbon Storage. Nature Education Knowledge. 3(10): 35. Available online: link (accessed on 20 August 2021).

Provin, T. and Pitt, J. (2017). Managing Soil Salinity. Retrieved from link.

Raskin, I. and Ensley, B.D. (2000). Phytoremediation of toxic metals. John Wiley and Sons. Phytoremediation of Toxic Metals. 2000 pp.x + 304 pp.

Ravindran, K.C., Venkatesan, K., Balakrishnan, V., Chellappan, K.P. and Balasubramanian, T. (2007). Restoration of saline land by halophytes for Indian soils. Soil Biology and Biochemistry. 39(10): 2661-2664.

Rhoades, J.D., Kandiah, A., Mashali, A.M. and van Schilfgaarde, J. (1992). Use of saline drainage waters for irrigation. Journal of the Irrigation and Drainage Division. 118(1): 34-51.

Sharma, D., Singh, J., Kumar, P., Yadav, S. and Sharma, S. (2020). Role of policy interventions in mitigating soil salinity in agriculture: A review. Land Degradation and Development. 31(11): 1327-1343.

Shrivastava, P. and Kumar, R. (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences. 22(2): 123-131.

Stamford, N.P., Figueiredo, M.V.B., Junior, S.S., Freitas, A.D.S., Santos, C.E.R.S. and Junior, M.A.L. (2015). Effect of gypsum and sulfur with Acidithiobacillus on soil salinity alleviation and on cowpea biomass and nutrient status as affected by PK rock biofertilizer. Scientia Horticulturae. 192: 287-292.

Wagner, K., Apostolakis, A., Daliakopoulos, I. and Tsanis, I. (2016). Can Tomato Inoculation with Trichoderma Compensate Yield and Soil Health Deficiency Due to Soil Salinity? In Proceedings of the EGU (European Geosciences Union) General Assembly Conference, Vienna, Austria, 17-22 April 2016; Geophysical Research Abstracts; EGU2016-1007; EGU: Vienna, Austria.

Wang, S.J., Chen, Q., Li, Y., Zhuo, Y.Q. and Xu, L.Z. (2017). Research on saline-alkali soil amelioration with FGD gypsum. Resources, Conservation and Recycling. 121: 82-92.

Wang, W., Xu, Y., Chen, T., Xing, L., Xu, K., Xu, Y., Ji, D., Chen, C. and Xie, C. (2019). Regulatory mechanisms underlying the maintenance of homeostasis in Pyropiahaitanensis under hypersaline stress conditions. Science of the Total Environment. 662: 168-179.

Wei, Z., Zhang, J., Huang, G., Xue, Y. and Li, Y. (2021). Evaluating the effectiveness of irrigation management policies in mitigating soil salinization under climate change. Journal of Environmental Management. 278: 111563.

Wheaton, A.D., McKenzie, B.M. and Tisdall, J.M. (2002). Management of a sodic soil for wine grape production. Australian Journal of Experimental Agriculture. 42(3): 333-339.

Xu, J., Tang, X., Shao, H. and Wang, H. (2015). The foliar spray of *Rhodopseudomonas palustris* grown under Stevia residue extract promotes plant growth via changing soil microbial community. Journal of Soils and Sediments. 16(4): 916-923.

Zeng, F., Lu, J., Yu, X. and Zhang, X. (2021). Effects of different irrigation methods on soil salinization and crop yields in arid regions: A review. Agricultural Water Management. 252: 106917.