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REVIEW

PLANT ADAPTATIONS TO SALINITY STRESS ANDVARIOUS AGRONOMIC MEASURES TO OVERCOME SALINITY STRESS

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Abstract: Salinity poses a significant challenge to plant productivity, particularly in arid and semi-arid regions, impacting approx. 1125 mha of land are affected by salinity at the present time, of which 76 mhaare affected by human-induced salinization and sodification, and 1.5 mha become unsuitable for agricultural production each year due to rising salinity levels. Salt stress affects plant growth through mechanisms such as water stress, ion toxicity, and oxidative damage. Plants respond to salinity through morphological adaptations like Root System Architecture (RSA), leaf anatomy modifications, and the presence of salt glands. Physiological adaptations include osmotic adjustment, ion homeostasis, and antioxidant defense systems. Understanding these adaptations is vital for developing effective agronomic measures, including soil management, crop rotation, genetic improvement, and water management. Employing these strategies can mitigate the negative effects of salinity stress, improving crop productivity and sustainability in saline environments. However, the escalating risk of soil salinization underscores the importance of interdisciplinary research and innovative approaches to address this global agricultural challenge.

Keywords: Adaptations, Management, Mitigation, Salinity, Stress

INTRODUCTION

Salinity stands as a formidable abiotic stress that greatly restricts plant productivity, especially in arid and semi-arid climates.(Ashraf and Harris, 2004). Currently, approximately 1125 mha of land are impacted by salinity globally, with 76 mhaaffected by salinization and sodification caused by human activities. Additionally, 1.5 mha of land become unsuitable for agricultural production annually due to increasing salinity levels. (M.S.Hossain,2019). Approximately one-fifth of irrigated lands worldwide are affected by soil salinization. (Morton *et al*., 2019). Salt stress refers to the adverse impact caused by the accumulation of high salt concentrations in the soil, resulting in the suppression of plant growth and development (Rahman *et al*., 2018). High salinity levels hinder the growth and progress of plants through several mechanisms, including water stress, cytotoxicity resulting from the over-absorption of ions like sodium (Na^+) and chloride (Cl^-), and disturbances in nutritional equilibrium.

Moreover, elevated salinity often leads to oxidative stress due to the production of reactive oxygen species (ROS). (Tsuganeet *al*., 1999; Hernandez *et al*., 2001; Isayenkov, 2012).The reaction of plant to salinity is typically categorized into two primary phases. The first phase involves a growth reduction independent of ion concentration, occurring within minutes to days. This phase results in stomatal closure and the inhibition of cell expansion, primarily observed in the shoot region.(Munns and Passioura, 1984; Munns and Termaat, 1986; Rajendran *et al*., 2009). Another phase unfolds gradually over days or weeks, focusing on the accumulation of cytotoxic ions. This accumulation hampers metabolic activities, triggers premature aging, and eventually leads to cell death.(Munns and Tester, 2008; Roy *et al*., 2014).Plants have evolved various strategies to cope with salinity stress, including both morphological and physiological adaptations. Understanding these adaptations is crucial for developing effective agronomic measures to mitigate the negative effects of salinity stress on crop plants. Some of them are discussed as following-

Morphological Adaptations

Morphological adaptations in plants play a crucial role in enhancing their resilience to salt stress by facilitating water and nutrient uptake, minimizing salt entry, and maintaining cellular integrity and functionality under challenging conditions. Certain morphological adaptations, such as thicker stems or leaves,Root System Architecture (RSA),salt glands etc., are discussed in details as following-

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Root System Architecture (RSA)

The manipulation of root system architecture plays a crucial role in the domestication and breeding of crop plants. Efficient utilization of water and nutrients from the soil significantly influences a plant's capacity to thrive in challenging or nutrient-deficient soils. Consequently, alterations in root system architecture can profoundly affect the ultimate yield of a crop. (de Dorlodot *et al*., 2007).Plants can extend their roots, increasing branching to explore a greater soil volume for water and nutrients, especially when faced with high salt concentrations near the soil surface. This enhances water and nutrient absorption. Root growth strategies adapt dynamically to various environmental stresses, both biological and non-biological, through the adjustment of specific characteristics such as root length, branching, alteration of root growth direction, and modifications in cell wall composition. In saline conditions, plants demonstrate phenotypic plasticity in their roots, dynamically adjusting both root system architecture (RSA) components and directional growth.(Dinneny, 2019; Julkowska *et al*., 2017; Korver *et al*., 2020).A more extensive root systemseems advantageous for plants as it enables them to penetrate deeper soil layers, facilitating the absorption of water and nutrients thus help in avoiding the upper salt layers of earth crust. (Franco *et al*., 2011). In Arabidopsis, moderate to high levels of salt, ranging from 75 to 150 mM NaCl, hinder the growth of both primary roots (PR) and lateral roots (LR). The characteristics of PR length, LR length, and LR number consistently decrease, although LR density exhibits significant variability in response to elevated salt levels across various studies, likely influenced by differences in nutrient concentrations utilized. (Li *et al*., 2021; Zolla, Heimer, and Barak, 2010).At salt concentrations exceeding 200 mM NaCl, emerging and young lateral roots (LRs) measuring less than 100 µm experience significantly less damage compared to primary roots (PR) and fully elongated lateral roots (> 400 µm) in viability assessments. The differenceobserved could be due to the higher level of NADPH oxidase-activated ROS induction in the young LR as compared to the PR(Ambastha *et al*., 2020).

In conditions of high salinity, plants have the capability to diminish their exposure to salt by altering the growth direction of their roots, a phenomenon known as halotropism. This response is observed not only in the roots of Arabidopsis but also in those of tomato (*Solanum lycopersicum*) and sorghum (*Sorghum bicolor*) seedlings, whether grown on agar media or in soil, when subjected to a salt gradient. Halotropism is achieved through the redistribution of auxin primarily by the PIN2 auxin efflux carrier located in the root tip. Upon exposure to a salt gradient, the presence of salt prompts the internalization of PIN2 on the side of the root facing higher salinity, leading to the redistribution of auxin and the directional bending of roots away from the salt source. (Galvan-Ampudia *et al*., 2013).

A significant anatomical change in the root system due to salt stress is the deposition of hydrophobic polymers such as cutin and suberin on the cell wall, polymers that are often associated with hydrophobic compounds (e.g., waxes). Different apoplastic adjustments in roots modify Na^+ fluxes to the shoots of olive trees exposed to up to 120 mM NaCl (Rossi *et al*., 2011). The Na^+ bypass flow in rice roots was reduced by the deposition of apoplastic barriers. These findings substantiated the role of root apoplastic barriers in plants' tolerance to salt stress (Krishnamurthy *et al*., 2011).

Leaf Anatomy

Thicker stems provide mechanical strength, allowing plants to withstand salinity stress and prevent water loss through transpiration. In saline environments, where soil conditions may be harsh, thicker stems help prevent bending or breaking due to wind or other forces. Thick stems often have specialized tissues (such as parenchyma cells) that store water. This adaptation helps plants endure periods of water scarcity by tapping into stored reserves. The vascular system within thicker stems efficiently transports water and nutrients between roots and leaves. This ensures a steady supply of resources even in challenging conditions. Leaves with thicker cuticles (waxy coatings) minimize water loss through transpiration. The cuticle acts as a barrier, preventing excessive evaporation from leaf surfaces. Thicker leaves typically have fewer stomata (tiny pores) on their surfaces. Stomata regulate gas exchange (including water vapor) during photosynthesis. By having fewer stomata, plants reduce water loss while still maintaining essential gas exchange. Some plants develop succulent leaves (thick and fleshy) to store water. These adaptations are common in arid regions and saline environments. (Liu *et al*., 2024)

Salt Glands and Bladders

Some halophytic plants, such as mangroves and saltbushes, have specialized structures called salt glands or bladders that secrete excess salt. This mechanism helps in maintaining lower salt concentrations in the plant tissues, thereby reducing the toxic effects of salts. Euhalophytes, plants thriving in saline environments, employ various mechanisms to cope with salt stress. These mechanisms include regulating their salt content through salt exclusion, which prevents salts from entering the vascular system, salt elimination, achieved by salt-secreting glands and hairs that actively remove salts to maintain salt concentration in leaves below a certain threshold, salt succulence, where the storage volume of cells progressively increases with salt uptake to maintain a constant salt concentration over time, and salt redistribution, wherein Na^+ and Cl^- ions are readily translocated in the phloem to redistribute high concentrations from actively transpiring leaves throughout the plant (Larcher, 2003).

Salt exclusion can occur in the roots, halting ion movement to the aerial parts of the plants. This mechanism is observed in certain glycophytes as well as most halophytes (salt-tolerant plants). The formation of saline vesicle glands in the epidermis aids in salt excretion, preventing salt buildup in various organs, including the leaves. Another example of an exclusion mechanism involves the accumulation of salts in older leaves, resulting in their death and subsequent shedding.

Succulence

Succulent plants store water in their fleshy tissues, allowing them to withstand drought and high salinity. In saline environments, excessive salt levels in the soil can disrupt water uptake by plants, leading to dehydration and impaired physiological functions. However, succulent plants have evolved mechanisms to counteract these effects. By accumulating water in specialized tissues, such as parenchyma cells or specialized storage organs like succulent leaves or stems, succulent plants create a reservoir that buffers against water loss and helps maintain cellular hydration. This stored water can be utilized during periods of water scarcity or osmotic stress caused by high soil salinity. Additionally, succulence allows for the dilution and compartmentalization of toxic ions, such as sodium and chloride, within the plant's vacuoles, reducing their harmful effects on cellular metabolism. Moreover, succulent tissues often have thick cuticles and reduced stomatal density, which minimize transpiration rates and water loss, further aiding in water conservation. Overall, succulence enhances plant resilience to salt stress by providing a means to store water, regulate ion concentrations, and minimize water loss, thereby sustaining vital physiological processes even in saline environments. (Siew and Klein, 1969; Slama*et al*., 2015)

Physiological Adaptations

Plants, being sessile, need to develop effective mechanisms to adapt to high-salt environments. Consequently, when exposed to salt stress signals, plants employ various strategies, including the regulation of ion balance, activation of osmotic stress pathways, modulation of plant hormone signaling, and adjustment of cytoskeleton dynamics and cell wall composition. Understanding the mechanisms behind these physiological and biochemical responses to salt stress could offer valuable insights for enhancing agricultural crop yields. Plants undergo physiological alterations to cope with salt stress. Common responses in species facing salt stress include enhanced osmotic adjustment, alterations in cell wall flexibility, and an increase in apo-plastic water content, which helps mitigate the adverse effects of salinity by maintaining leaf turgidity. Numerous compounds involved in osmotic regulation in plants are well-documented, such as carbohydrates (e.g., sucrose, sorbitol, mannitol, glycerol, pinitol), nitrogen-containing molecules (e.g., proteins, betaine, glutamate, aspartate, glycine, proline, choline, 4-gamma aminobutyric acid), and organic acids (e.g., malate and oxalate). Proline (Pro) and glycine betaine (GB) are considered crucial and effective compatible solutes among organic osmolytes, helping minimize the detrimental effects of salt stress and promoting plant growth.

Osmotic Adjustment

Osmotic adjustment stands as a vital physiological strategy employed by plants to manage salinity stress. Plants growing in saline soils regulate the intake of Na^+ and Cl^- ions to prevent ion toxicity while ensuring an adequate supply of solutes for osmotic adjustment Within plants, osmotic adjustment relies on two types of osmolytes: organic solutes like sucrose, polyols, glycine betaine, and proline, and inorganic ions such as K^+, Ca^{2+}, Na^+, Mg^{2+}, and Cl^-.

Plants accumulate compatible solutes including proline, glycine betaine, and sugars to uphold cellular turgor and facilitate water uptake in saline environments. This serves to prevent dehydration and uphold the integrity of plant cells. They accumulate solutes in quantities matching the increased ion concentrations in the soil solution to achieve osmotic adjustment, thus maintaining cell turgor and organelle volume within growing plant cells. (Munns and Gilliham, 2015).

Ion Homeostasis

Balancing ion levels and effectively neutralizing O_{2-} and H_2O_2 reactive oxygen species (ROS) have emerged as crucial mechanisms for enhancing salt tolerance in plants (Hasanuzzaman*et al*., 2021; Li *et al*., 2022). Excessive salt, including sodium and chloride ions, can disrupt numerous cellular functions. To counteract this, plants utilize ion transporters and channels to manage the intake, segregation, and expulsion of ions, thereby reducing the detrimental impact of salts. Adaptation to high salinity involves maintaining cellular ion homeostasis, which includes regulating the uptake of toxic sodium ions (Na^+) and chloride ions (Cl^-), preventing their transport to the aerial parts of plants, and sequestering these ions in vacuoles.

Ion transporters have long been recognized for their roles in maintaining ion homeostasis. Sodium ions (Na^+) enter the cell through various voltage-dependent selective and non-selective ion channels. The high concentration of Na^+ in the plasma membrane is balanced by potassium ion (K^+) uptake via various potassium-importing channels, salt exclusion mechanisms, or Na^+ sequestration in vacuoles. Therefore, high-affinity potassium transporters, the salt overly sensitive pathway, the well-defined Na^+ exclusion pathway that exports Na^+ from cells into the xylem, and tonoplast-localized cation transporters that compartmentalize Na^+ in vacuoles are necessary to enhance plant adaptability to saline soil. (Malakar and Chattopadhyay, 2021)

Antioxidant Defense System

High salinity can lead to the production of reactive oxygen species (ROS), which can damage cellular components. Plants have developed antioxidant defense systems, including enzymes like superoxide dismutase, catalase, and peroxidase, to detoxify ROS and protect against oxidative stress. Plants utilize antioxidants to scavenge reactive oxygen species (ROS), coordinating with both non-enzymatic antioxidants such as ascorbate (AsA), glutathione (GSH), phenolic compounds, flavonoids, alkaloids, α-tocopherol, non-protein amino acids, and enzymatic antioxidants including superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), dehydro-ascorbate reductase (DHAR), monodehydroascorbate reductase (MDHAR), glutathione peroxidase (GPX), glutathione reductase (GR), glutathione S-transferase (GST), peroxidase (POD/POX), polyphenol oxidase (PPO), peroxiredoxin (PRX), and thioredoxin (TRX). These antioxidants collectively safeguard plants from oxidative harm. (M. Hasanuzzaman *et al*.,2020; S. Sachdev *et al*., 2021)

Cell compositions

The capacity of plant to endure salt stress is bolstered by cellular reactions prompted by salt, including the deposition of polysaccharides, alterations in pectin, and adjustments in microfibril orientation within the cell wall. (Byrt *et al*., 2018). The composition of the cell wall can undergo dynamic changes in response to both biotic and abiotic stresses, exhibiting variations among different species and cell types. (Feng*et al*., 2016; Vaahtera *et al*., 2019; Wolf *et al*., 2012)Recent research indicates that genes responsible for biosynthesis of cell wall constituents, such as lignin (A. Q. Duan *et al*., 2020), arabinose (C. Zhao *et al*., 2019), and galactan (Yan *et al*., 2021), play a role in enhancing salt tolerance.

Certain root morphologies, such as the development of barrier tissues like Casparian strips and suberized layers, can prevent the entry of excessive salts into the plant, thus reducing their toxic effects. Alterations in root structural barriers through changes in cell wall composition could potentially mitigate water loss and restrict the entry of Na^+ ions into roots (Byrt*et al*., 2018). These modifications encompass lignification and suberization in both the endodermis and exodermis (Kajala*et al*., 2021). Lignification in higher plants confers strength and hydrophobic properties to the secondary cell walls, thereby establishing a protective barrier against various stresses (Q. Zhao, 2016).

Euhalophytes have the capability to accumulate salt in their cell sap to a level where their osmotic potentials become lower than that of the soil solution. Besides salts, the accumulation of soluble carbohydrates is also significant in maintaining a low osmotic cell sap potential. Furthermore, the protoplasm's ability to endure high salt concentrations relies on the selective compartmentalization of ions entering the cell. Most of the salt ions are stored in the vacuoles through inclusive mechanisms.Halophytes exhibit an increased abundance of mitochondria, suggesting a heightened energy demand for survival in saline environments (Slama*et al*., 2015). Moreover, halophytes display reduced accumulation of sodium and chloride ions in their cytoplasms, enabling their chloroplasts to endure salinity shocks (J.C. Cushman, 1990).

Phytohormones

The application of exogenous plant growth regulators is widely recognized for its ability to enhance stress tolerance across various plant species (S.I.M. Houimli*et al*., 2008). ABA has been identified as beneficial in mitigating plant salt stress, particularly under conditions of low water availability. Additionally, ABA production within plant cells is linked to ethylene synthesis during salt stress, with the interaction between these two stress hormones evident in vegetative growth and seed germination responses under salt stress. Ethylene plays a regulatory role in ABA concentration during root inhibition induced by salt stress, although the opposite effect has been observed in seed germination scenarios (Thussagunpanit*et al*., 2015). Salicylic acid has demonstrated a defensive function in plants under stress, acting as a signaling molecule to prompt adaptation to challenging environmental conditions.

Auxin, acting as a chemical messenger, modulates gene expression via a group of transcription factors known as Auxin Response Factors (ARFs), which possess distinct functions. Multiple studies have underscored the significance of ARFs in orchestrating plant responses to drought and salinity stress. These ARFs play diverse roles, including the regulation of soluble sugar levels, promotion of root growth, and maintenance of chlorophyll content under conditions of drought and salinity stress, aiding plants in their adaptation to these environmental challenges (Verma *et al*., 2022).

Agronomic Measures to Mitigate Salinity Stress:

The implementation and adjustment of particular agricultural, technical, and technological practices can also provide a comprehensive range of solutions for managing and mitigating the adverse impacts of salinity on crops, encompassing land, water, and crop management strategies. (Ondrasek and Rengel, 2021). Various agro-hydrotechnical (soil and water conservation, reduced tillage, mulching, rainwater harvesting, irrigation and drainage, control of seawater intrusion), biological (agroforestry, multi-cropping, cultivation of salt-resistant species, bacterial inoculation, promotion of mycorrhiza, grafting with salt-resistant rootstocks), chemical (application of organic and mineral amendments, phytohormones), bio-ecological (breeding, desalination, application of nano-based products, seed biopriming), and/or institutional solutions (salinity monitoring, integrated national and regional strategies) are very effective against salinity/salt stress and numerous other constraints. Some of the agronomic measures are discussed as following-

Soil Management

Adding organic matter, such as compost or manure, can improve soil structure and fertility, enhancing its ability to retain moisture and nutrients. Gypsum application can help in displacing sodium ions and improving soil structure. Plant scientists are implementing various techniques to mitigate excessive soil salinity, including sub-soiling, sand mixing, seed bed preparation, and salt scraping, alongside modern agronomic methods, hydrophilic polymers, gypsum, sulfur acids, green manuring, humic substances, farmyard manures, irrigation systems, and cultivation of salt-tolerant crops. (Shahid *et al*., 2018; S, Shilev, 2020; Meena *et al*., 2020; Bhowmik *et al*., 2021). K fertilization could be effective to improve rice production and nutrient uptake in coastal saline soil of Bangladesh while maintaining a high K+/Na+ ratio. (Akter*et al*., 2023).

In recent times, organic amendments like vermicompost (VC), vermi-wash (VW), biochar (BC), plant growth-promoting rhizobacteria (PGPR), and bio-fertilizers (BF) have become increasingly popular for mitigating the detrimental effects of soil salinity.(Imran *et al*., 2022; Kanwal *et al*., 2018; Rasheed *et al*., 2020; Hannan *et al*., 2020; Ali *et al*., 2021). Vermicompost (VC) boosts the morphological characteristics, chlorophyll levels, antioxidant enzyme functions, and enhances the salt tolerance of maize plants. (Alamer*et al*., 2022). Numerous studies have indicated that bio-fertilizers (BF) and biochar (BC) bolster plant growth under salinity stress by enhancing antioxidant enzyme activities and minimizing oxidative damage across various plant species. Khalilzadeh *et al*., 2017; Ekinci*et al*., 2022; Imran *et al*., 2022).

Moreover, the inoculation of plant growth-promoting rhizobacteria (PGPR) under salt stress expedites microbial population growth and gene expression in the rhizosphere, leading to heightened biomass production and improved salt tolerance in diverse plant species. (Hoque *et al*., 2022; Kumar *et al*., 2020; Chauhan *et al*., 2019). Organic amendments alleviate salt stress through a multitude of mechanisms, including the regulation of ionic balance, enhancement of antioxidant enzyme activities, and mitigation of oxidative damage. Several studies have demonstrated that PGPR and BC mitigate the adverse effects of salinity by augmenting photosynthetic rates, antioxidant enzyme functions, accumulation of secondary metabolites, and reduction of reactive oxygen species (ROS) levels in plants. (Hoque *et al*., 2022; Parkash and Singh, 2020; Kerbab*et al*., 2021; Ha-Tran *et al*., 2021). Organic amendments like vermicompost (VC) and vermi-wash (VW) contain a plethora of plant growth-promoting constituents such as micronutrients, macronutrients, vitamins, enzymes, and hormones, which have been shown to alleviate the detrimental effects of salt stress on plants.

The application of vermicompost (VC) mitigated salt-induced plant injuries in saline soil by elevating relative water content, stomatal conductance, chlorophyll-a levels, as well as superoxide dismutase (SOD), ascorbate peroxidase (APX), and catalase (CAT) activities. Additionally, it led to a reduction in electrolyte leakage and malondialdehyde (MDA) levels. (Hannan *et al*., 2020).Furthermore, numerous studies have reported that VC and VW reduce soil salinity by enhancing antioxidant enzyme activities and diminishing electrolyte leakage and oxidative stress. (Pérez-Gómez *et al*., 2017; Ruiz-Lau *et al*., 2020). Similarly, BF, akin to other organic supplements, contributes to ameliorating the soil environment by fixing atmospheric nitrogen, solubilizing phosphate and potassium, releasing plant growth-regulating substances, producing antibiotics, and decomposing organic matter, all of which collectively enhance plant tolerance to salinity stress.Adding sand to a soil with a very fine texture (clayey) can enhance its texture and mitigate salinity stress. However, this method can be quite costly and impractical when implemented on a large scale. (Zaman *et al*., 2018).

Crop Rotation and Selection

Crop rotation with deep-rooted species can also help in breaking the cycle of salt accumulation in the soil. The spatial and temporal adjustment of cropping patterns, such as planting salt-resistant crops or varieties in specific locations during periods of high evapotranspiration demand, such as low-lying terrain positions, has been validated as a highly effective approach to mitigate soil salinity and associated environmental challenges in arid and semi-arid agricultural systems. For example, employing mixed cropping systems, such as agroforestry or combining forage and cereal crops, instead of monocropping, has been demonstrated to be more effective in restoring soil carbon and nitrogen levels. (Amoah *et al*., 2015)

Genetic Improvement

Breeding programs aimed at developing salt-tolerant crop varieties can help in increasing crop productivity in saline environments. Genetic engineering techniques can also be used to introduce genes responsible for salt tolerance into commercial crops. The utilization of microRNAs (miRNAs) is widely acknowledged as a significant strategy influencing post-transcriptional gene regulation across diverse environmental conditions, including salinity.

The interaction between salt stress and gene expression is heavily modulated by post-transcriptional mechanisms, as various gene transcripts undergo differential regulation by miRNAs during salt stress. Additionally, miRNAs play pivotal roles in numerous plant processes, including embryogenesis, morphogenesis, life cycle stage transitions, flower development, fruit ripening, anthocyanin production, vegetative and reproductive phase shifts, tillering, branching, and enhancement of salt tolerance. (W. Islam *et al*., 2022; C. Cao *et al*., 2018; L. Kuang*et al*., 2019)

Water Management

Salinity from irrigation arises when frequent irrigation with groundwater leads to the accumulation of salts on the soil surface. Employing efficient irrigation techniques, such as drip irrigation or mulching, can diminish water loss via evaporation and leaching, thereby conserving water and limiting the accumulation of salts in the root zone. Efficient use of saline water resources, such as using saline groundwater for irrigation in salt-tolerant crops, can help in reducing the pressure on freshwater sources and improving agricultural sustainability in saline-affected regions. Among the most effective strategies are precise water management practices, including (i) the utilization of modern, low-pressure, and localized irrigation techniques, and if required, (ii) the implementation of surface or underground drainage systems. Both approaches are instrumental in regulating salinized groundwater levels to keep them below the critical root zone and facilitate the leaching of accumulated salts from the rhizosphere. (G. Ondrasek, 2019; Ondrasek*et al*., 2014).

Enhancing leveling, preferably through laser-guided techniques, facilitates a more consistent distribution of water. Subsoiling, also known as "deep ripping," aims to enhance soil properties at deeper layers, particularly where a dense soil layer or hardpan exists, thereby restricting root penetration and water infiltration. Salts present at the soil surface can be scraped off and removed to prevent further impact on plants following rainfall. A drainage system, which includes both surface and subsurface components, can effectively lower the soil water table to a safer level, thus preventing the harmful impacts of excessive water which contain salts within the typical plant root zone. At the agricultural level, drainage serves as a vital moisture control system, essential for preserving optimal moisture levels and regulating salt balance within the root zone. When implementing an irrigation system, it is important that it allows for regular, consistent, and effective water distribution while minimizing percolation losses, all without compromising the necessary leaching process.

Moreover, an effective irrigation system should refrain from using saline water during the sensitive seed germination stage. Whenever feasible and high-quality water is accessible, farmers should consider utilizing recycled water for irrigation purposes. Utilizing saline or brackish water typically elevates soil salinity in the root zone. To mitigate this salt accumulation, additional water beyond the crop's evapotranspiration requirement can be applied. This surplus water generally helps to push salts beneath the root zone. The necessary quantities of water for this leaching process, referred to as the leaching requirement (LR), can be calculated. (Zaman *et al*., 2018)

Nano Technology

The utilization of nanotechnology-based solutions is rapidly expanding across various domains of human activities, including agricultural ecosystems, particularly in crop food production. (Ondrasek*et al*., 2021). For example, the application of specific nanomaterials such as single-/multi-walled carbon-based nanotubes, polymeric chitosan, graphene, fullerol, and fullerene, alongside nanoparticles like nano-fertilizers and nano-pesticides, as well as nano-based technologies and methodologies such as nanofiltration of brackish and/or grey water resources for irrigated cropping, and the transport and deposition of trace elements within crop tissues, have emerged as highly promising strategies and alternatives. These innovations show potential in alleviating nutrient disorders and enhancing crop food production under various abiotic conditions, including excessive salinity and induced salt disorders. (Khot*et al*., 2012; Ditta and Arshad, 2016; Dimpka*et al*., Pandey *et al*., 2018)

CONCLUSION

In conclusion, understanding the mechanisms of plant adaptation to salinity stress and implementing agronomic measures can help in mitigating the negative effects of salinity stress on crop plants. By combining morphological and physiological adaptations with agronomic practices, it is possible to improve crop productivity and sustainability in saline environments. The utilization of recycled water for irrigation, inadequate fertilization practices, and the degradation of agricultural lands are progressively heightening the risk of soil salinization (Jha *et al*., 2019). Consequently, salinity, as a major abiotic stressor, results in considerable yield reductions in agricultural crops globally. To address the decline in crop productivity due to the escalating issue of salinity stress, diverse strategies have been adopted. Interdisciplinary research breakthroughs in numerous model and crop plants have enhanced our comprehension of the intricate agronomic practices and molecular mechanisms involved.

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