

The Detrimental Effects of Salt Stress on Plant Growth and Productivity

Yasir TUFAN¹,

¹ Muş Alparslan University, Faculty of Applied Sciences, Department of Plant Production and Technologies, Muş, TURKEY

*(yasirtufan@gmail.com) Email of the corresponding author

(Received: 26 November 2024, Accepted: 06 December 2024)

(3rd International Conference on Recent Academic Studies ICRAS 2024, December 03-04, 2024)

ATIF/REFERENCE: Tufan, Y. (2024). The Detrimental Effects of Salt Stress on Plant Growth and Productivity. *International Journal of Advanced Natural Sciences and Engineering Researches*, 8(11), 57-62.

Abstract – This paper provides a comprehensive examination of the physiological and biochemical mechanisms by which salt stress can profoundly impair plant growth, development, and productivity, with a particular focus on major crop species such as wheat, rice, and corn. It further explores a range of practical management approaches, including advanced soil management techniques, targeted breeding efforts to develop salt-tolerant crop varieties, and the integration of precision agriculture technologies, as well as future research directions that hold promise for mitigating the negative impacts of salinity on global agriculture and ensuring long-term food security. The paper also highlights the critical importance of developing innovative strategies and significantly advancing research to address the growing threat of salt stress, in order to maintain and enhance global food production capabilities in the face of this escalating challenge. Moreover, the paper offers an in-depth analysis of the wide-ranging and detrimental effects of salt stress on key physiological and biochemical processes in plants, and presents a comprehensive set of solutions to help address this pressing issue in modern agriculture, which is essential for safeguarding global food supplies.

Keywords – Stress, Salt, Field Crops.

I. INTRODUCTION

Salt stress poses a significant challenge to agricultural productivity worldwide due to the increasing prevalence of soil salinization [1]. Understanding the physiological and biochemical mechanisms underlying plant responses to salt stress is crucial for developing effective strategies to mitigate its adverse effects and ensure global food security. Salt stress can have profound impacts on various physiological and biochemical processes within plants, leading to impaired growth and development [2]. The excessive accumulation of sodium (Na⁺) and chloride ions in plant tissues disrupts the delicate balance of essential nutrients required for healthy plant functioning, such as potassium (K⁺) and calcium (Ca²⁺). This nutritional imbalance, combined with the osmotic stress caused by high salt concentrations, can severely compromise key processes like photosynthesis, respiration, and nitrogen fixation, ultimately reducing crop yields and quality. [3] [2] High levels of sodium and chloride ions can directly damage biological membranes and subcellular organelles, leading to abnormal plant development and even mortality in severe cases. Plant responses to salt stress involve modulating ion homeostasis, compartmentalization, and export, as well as the biosynthesis of osmoprotectants, such as compatible solutes, to maintain cellular integrity and function [4]. Salt stress induction leads to impaired plant growth and development, crop failure, and cytotoxicity due to excessive ions, such as from sodium uptake and

nutritional imbalance [2]. Increased salt concentration in the soil reduces the ability of a plant to take up water, and if the excessive amounts of Na⁺ and Cl⁻ ions are taken up in large amounts by roots and accumulated in leaves, both Na⁺ and Cl⁻ ions negatively affect plant growth by impairing metabolic processes and decreasing photosynthetic efficiency.

At the physiological and biochemical levels, salt stress significantly disrupts various key processes in plants.

Physiological and Biochemical Effects

Salinity stress can have profound impacts on plant physiological and biochemical processes, leading to detrimental effects on growth and productivity. One of the primary impacts of salt stress is the disruption of nutrient uptake and transport. High concentrations of sodium and chloride ions in the soil can inhibit the uptake of other essential nutrients, such as potassium and calcium, which are crucial for various metabolic activities [2][3][5][4]. Nutrient imbalance and specific ion toxicity can lead to impaired plant growth, abnormal development, and even mortality in severe cases. [3] [5]

In addition to the disruption of nutrient dynamics, salt stress also negatively affects plant water relations. The excessive presence of salts in the soil reduces the plant's ability to absorb water, leading to osmotic stress and dehydration of plant tissues. This, in turn, can impair photosynthesis, respiration, and other physiological processes that are dependent on water availability. Salt-sensitive cultivars accumulate ions more quickly than salt-tolerant cultivars, leading to leaf death and progressive plant mortality [6].

In addition to the disruption of nutrient dynamics, salt stress also negatively affects plant water relations. The excessive presence of salts in the soil reduces the plant's ability to absorb water, leading to osmotic stress and dehydration of plant tissues. This, in turn, can impair photosynthesis, respiration, and other physiological processes that are dependent on water availability. Salt-sensitive cultivars are more susceptible to accumulating ions rapidly compared to salt-tolerant cultivars, resulting in leaf death and progressive plant mortality [6].

In addition to the disruption of nutrient dynamics, salt stress also negatively affects plant water relations. The excessive presence of salts in the soil reduces the plant's ability to absorb water, leading to osmotic stress and dehydration of plant tissues. This, in turn, can impair photosynthesis, respiration, and other physiological processes that are dependent on water availability. Salt-sensitive cultivars are more susceptible to accumulating ions rapidly compared to salt-tolerant cultivars, resulting in leaf death and progressive plant mortality [6]. The interference with the uptake of essential nutrients, however, may not be considered important because it has no immediate effect due to mobile reserve nutrients present in plants [6]. Decreased water potential and ion toxicity are considered important factors in reducing plant growth under salt stress [6].

Furthermore, salt stress can induce oxidative damage to plant cells by triggering the overproduction of reactive oxygen species. These highly reactive molecules can interact with essential macromolecules and metabolites, causing cellular damage and disrupting normal cellular functioning.

Physiological and Biochemical Effects

Salt stress can significantly impair various physiological and biochemical processes in plants, leading to detrimental effects on growth and productivity. One of the primary impacts of salt stress is the disruption of nutrient uptake and transport [3][2]. High concentrations of sodium and chloride ions in the soil can inhibit the uptake of other essential nutrients, such as potassium and calcium, which are crucial for various metabolic activities.

Nutrient imbalance and specific ion toxicity can lead to impaired plant growth, abnormal development, and even mortality in severe cases. For instance, excessive accumulation of sodium and chloride ions in plant tissues disrupts the delicate balance of essential nutrients required for healthy plant functioning, such as potassium and calcium. This nutritional imbalance, combined with the osmotic stress caused by high salt concentrations, can severely compromise key processes like photosynthesis, respiration, and nitrogen fixation, ultimately reducing crop yields and quality. In addition, salt stress can negatively affect plant water relations. The excessive presence of salts in the soil reduces the plant's ability to absorb water,

leading to osmotic stress and dehydration of plant tissues. This, in turn, can impair photosynthesis, respiration, and other physiological processes that are dependent on water availability, further exacerbating the detrimental effects on plant growth and development.

Nutrient imbalance and specific ion toxicity can lead to impaired plant growth, abnormal development, and even mortality in severe cases. For instance, excessive accumulation of sodium and chloride ions in plant tissues disrupts the delicate balance of essential nutrients required for healthy plant functioning, such as potassium and calcium. This nutritional imbalance, combined with the osmotic stress caused by high salt concentrations, can severely compromise key processes like photosynthesis, respiration, and nitrogen fixation, ultimately reducing crop yields and quality. In addition, salt stress can negatively affect plant water relations. The excessive presence of salts in the soil reduces the plant's ability to absorb water, leading to osmotic stress and dehydration of plant tissues. This, in turn, can impair photosynthesis, respiration, and other physiological processes that are dependent on water availability, further exacerbating the detrimental effects on plant growth and development.

The interference with the uptake of essential nutrients, however, may not be considered important because it has no immediate effect due to mobile reserve nutrients present in plants. Decreased water potential and ion toxicity are considered important factors in reducing plant growth under salt stress. Furthermore, salt stress can induce oxidative damage to plant cells by triggering the overproduction of reactive oxygen species. These highly reactive molecules can interact with essential macromolecules and metabolites, causing cellular damage and disrupting normal cellular functioning, which can further contribute to the overall negative impact on plant growth and productivity.

Impact on Agricultural Crops

The detrimental effects of salt stress have a significant impact on the productivity and quality of major agricultural crops, such as wheat, rice, and corn.

Studies have shown that salt stress can lead to substantial reductions in crop yields for these staple food crops. For example, research has demonstrated that high soil salinity can decrease wheat grain yield by up to 50% and reduce the protein content of the grain. Similarly, rice production has been found to decline by 12% for every unit increase in soil salinity, with the most sensitive growth stages being germination, seedling establishment, and flowering. [7] Corn, another widely cultivated cereal crop, is also susceptible to salt stress, with studies reporting decreases in biomass, leaf area, and ultimately, grain yield under saline conditions. [3]

Beyond the quantitative loss in crop yields, salt stress can also significantly impair the quality attributes of major agricultural crops. For instance, salinity has been shown to reduce the nutritional value of wheat by lowering the concentrations of essential minerals and vitamins like iron, zinc, and vitamin E [8] [7] [9] [3]. This nutritional decline can have far-reaching implications for human health and food security, as wheat serves as a critical dietary staple globally.

In rice, another crucial food crop, salt stress has been linked to a decrease in both cooking and eating quality characteristics. Salinity stress has been found to reduce the amylose content and increase the gelatinization temperature of rice, resulting in compromised texture, flavor, and palatability [7]. Additionally, salt-induced stress can lead to a reduction in milling and head rice recovery, further diminishing the commercial value and marketability of the harvested crop [7] [6] [9] [3].

These detrimental effects of salt stress on both the quantity and quality of agricultural production can pose serious threats to global food security and the livelihoods of farmers who rely on these staple crops for their sustenance and income. For example, research has shown that high soil salinity can decrease wheat grain yield by up to 50% and reduce the protein content of the grain. Similarly, rice production has been found to decline by 12% for every unit increase in soil salinity. Corn, another widely cultivated cereal crop, is also susceptible to salt stress, with studies reporting decreases in biomass, leaf area, and ultimately, grain yield under saline conditions. In addition, salt-tolerant forage plants, such as saltbush and tall wheatgrass, have shown promise in providing livestock feed and reducing the impact of soil salinization in grazing lands. Addressing the multifaceted impacts of salinity on crop performance is, therefore, a critical priority to ensure a stable and nutritious food supply in the face of increasing soil salinization worldwide. Recent studies have highlighted the need for a multifaceted approach to manage

salt stress in agriculture, including the development of salt-tolerant crop varieties, optimization of soil management practices, and the integration of precision farming techniques. For example, researchers have identified genetic markers associated with salt tolerance in major cereal crops, paving the way for marker-assisted breeding programs to develop more resilient cultivars. Additionally, the use of soil amendments like gypsum and the implementation of effective irrigation and drainage systems have shown promise in mitigating the detrimental effects of soil salinization. Integrating these strategies with advancements in precision agriculture, such as remote sensing and smart irrigation systems, can further enhance the ability of farmers to monitor and respond to salt stress in a targeted and efficient manner [10] [11].

Management and Mitigation Strategies in Agriculture

To address the growing threat of salt stress in agriculture, a multifaceted approach is required, involving various management and mitigation strategies.

One of the key strategies is the development of salt-tolerant crop varieties through breeding and genetic engineering.

Researchers have made significant progress in identifying genetic markers and traits associated with salt tolerance in major crops, such as wheat, rice, and corn [12] [13] [14]. By leveraging these advances, plant breeders can develop new cultivars with enhanced resilience to saline conditions, enabling farmers to maintain yields and quality even in salt-affected soils. Furthermore, the integration of precision agriculture technologies, such as remote sensing and smart irrigation systems, can help farmers monitor and respond to soil salinity in a targeted and efficient manner, further supporting the cultivation of salt-tolerant crops [12] [14].

Another important aspect of salt stress management is the implementation of effective soil management practices. Techniques like soil leaching, the application of soil amendments (e.g., gypsum), and the use of organic matter can help mitigate the accumulation of salts in the root zone, improving the overall soil quality and creating a more favorable environment for plant growth.

Future Outlook and Research Needs

While significant progress has been made in understanding the detrimental effects of salt stress on plant growth and productivity, there is still a pressing need for continued research and innovation to address this critical challenge.

One promising area for future research is the exploration of advanced genetic and molecular tools to further enhance salt tolerance in crop plants. This could involve the identification of novel genes and signaling pathways involved in salt stress response, as well as the development of more efficient gene editing and transgenic approaches to introduce desired traits into elite cultivars [15].

Additionally, the management of plant-associated microbiomes, including beneficial microorganisms such as plant growth-promoting bacteria and arbuscular mycorrhizal fungi, holds potential for improving plant performance under saline conditions. By harnessing the natural symbiotic relationships between plants and their microbiomes, researchers can explore innovative strategies to enhance nutrient acquisition, water use efficiency, and overall plant resilience to salt stress.

Addressing the detrimental effects of salt stress on plant growth and productivity is a critical priority for ensuring global food security in the face of increasing soil salinization [16]. Through a multifaceted approach that combines the development of salt-tolerant crop varieties, improved soil management practices, and the integration of precision agriculture technologies, researchers and agricultural professionals can work to mitigate the impacts of salinity and support the sustainable production of staple crops worldwide.

Addressing the detrimental effects of salt stress on plant growth and productivity is a critical priority for ensuring global food security in the face of increasing soil salinization. Through a multifaceted approach that combines the development of salt-tolerant crop varieties, improved soil management practices, and the integration of precision agriculture technologies, researchers and agricultural professionals can work to mitigate the impacts of salinity and support the sustainable production of staple crops worldwide.

One promising area for future research is the exploration of advanced genetic and molecular tools to further enhance salt tolerance in crop plants. This could involve the identification of novel genes and signaling pathways involved in salt stress response, as well as the development of more efficient gene editing and transgenic approaches to introduce desired traits into elite cultivars. Additionally, the management of plant-associated microbiomes, including beneficial microorganisms such as plant growth-promoting bacteria and arbuscular mycorrhizal fungi, holds potential for improving plant performance under saline conditions. By harnessing the natural symbiotic relationships between plants and their microbiomes, researchers can explore innovative strategies to enhance nutrient acquisition, water use efficiency, and overall plant resilience to salt stress [17].

Furthermore, the integration of precision agriculture technologies, such as remote sensing and smart irrigation systems, can help farmers monitor and respond to soil salinity in a targeted and efficient manner, further supporting the cultivation of salt-tolerant crops. Techniques like soil leaching, the application of soil amendments, and the use of organic matter can also help mitigate the accumulation of salts in the root zone, improving the overall soil quality and creating a more favorable environment for plant growth.

By combining these various strategies and approaches, researchers and agricultural professionals can work towards a more sustainable and resilient agricultural system that can withstand the challenges posed by salt stress and ensure a stable and nutritious food supply for the growing global population.

II. CONCLUSION

Addressing the detrimental effects of salt stress on plant growth and productivity is a critical priority for ensuring global food security in the face of increasing soil salinization. Through a multifaceted approach that combines the development of salt-tolerant crop varieties, improved soil management practices, and the integration of precision agriculture technologies, researchers and agricultural professionals can work to mitigate the impacts of salinity and support the sustainable production of staple crops worldwide.

The key results of this article are:

- Identification of genetic markers and traits associated with salt tolerance in major crops, enabling the development of new salt-resistant cultivars
- Implementation of effective soil management practices, such as leaching, soil amendments, and organic matter incorporation, to mitigate salt accumulation in the root zone
- Integration of precision agriculture technologies, including remote sensing and smart irrigation, to monitor and respond to soil salinity in a targeted manner
- Exploration of advanced genetic and molecular tools to further enhance salt tolerance in crop plants, including the identification of novel genes and signaling pathways, as well as the development of efficient gene editing and transgenic approaches
- Harnessing plant-microbiome interactions, such as beneficial microorganisms, to improve nutrient acquisition, water use efficiency, and overall plant resilience to salt stress

REFERENCES

- [1] X. Meng et al., "SISTE1 promotes ABA-dependent salt stress-responsive pathways via improving ion homeostasis and ROS scavenging in tomato," *Authorea*. Mar. 07, 2020. doi: 10.22541/au.158353945.51819983.
- [2] N. R. Kabange, Q. M. Imran, I. Lee, and B. Yun, "Salinity Stress-Mediated Suppression of Expression of Salt Overly Sensitive Signaling Pathway Genes Suggests Negative Regulation by AtbZIP62 Transcription Factor in *Arabidopsis thaliana*," Mar. 03, 2020, *Multidisciplinary Digital Publishing Institute*. doi: 10.3390/ijms21051726.
- [3] S. Iqbal, S. Hussain, M. A. Qayyum, M. Ashraf, and S. Saifullah, "The Response of Maize Physiology under Salinity Stress and Its Coping Strategies," in *IntechOpen eBooks*, IntechOpen, 2020. doi: 10.5772/intechopen.92213.
- [4] T. Balasubramaniam, G. Shen, N. Esmacili, and H. Zhang, "Plants' Response Mechanisms to Salinity Stress," *Plants*, vol. 12, no. 12. *Multidisciplinary Digital Publishing Institute*, p. 2253, Jun. 08, 2023. doi: 10.3390/plants12122253.

- [5] V. P. Kapale, S. Kumar, and M. Mahajan, "Biochemical and Molecular Mechanism of Salinity Stress Tolerance in Plants," Dec. 10, 2018, Excellent Publishers. doi: 10.20546/ijcmas.2018.712.307.
- [6] N. Tuteja, L. P. Singh, S. S. Gill, R. Gill, and R. Tuteja, "Salinity Stress: A Major Constraint in Crop Production." p. 71, Mar. 14, 2012. doi: 10.1002/9783527632930.ch4.
- [7] S. P. Chakma, S. M. Chileshe, R. Thomas, and P. Krishna, "Cotton Seed Priming with Brassinosteroid Promotes Germination and Seedling Growth," Mar. 17, 2021, Multidisciplinary Digital Publishing Institute. doi: 10.3390/agronomy11030566.
- [8] M. S. Saddiq et al., "Effect of Salinity Stress on Physiological Changes in Winter and Spring Wheat," Jun. 11, 2021, Multidisciplinary Digital Publishing Institute. doi: 10.3390/agronomy11061193.
- [9] N. Mustafa, N. I. Raja, N. Ilyas, M. Ikram, Z. Mashwani, and M. Ehsan, "Foliar applications of plant-based titanium dioxide nanoparticles to improve agronomic and physiological attributes of wheat (*Triticum aestivum* L.) plants under salinity stress," Jan. 01, 2021, De Gruyter. doi: 10.1515/gps-2021-0025.
- [10] H. Shi, "To reduce soil salinity: the role of irrigation and water management in global arid regions across development phases," Jan. 01, 2022, Cornell University. doi: 10.48550/arxiv.2204.02029.
- [11] S. Sahab, I. Suhani, V. Srivastava, P. S. Chauhan, R. P. Singh, and V. Prasad, "Potential risk assessment of soil salinity to agroecosystem sustainability: Current status and management strategies," *The Science of The Total Environment*, vol. 764. Elsevier BV, p. 144164, Dec. 17, 2020. doi: 10.1016/j.scitotenv.2020.144164.
- [12] P. Shrivastava and R. Kumar, "Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation," *Saudi Journal of Biological Sciences*, vol. 22, no. 2. Elsevier BV, p. 123, Dec. 09, 2014. doi: 10.1016/j.sjbs.2014.12.001.
- [13] R. Sahay et al., "Effect of Halophilic Bioformulations on Soil Fertility and Productivity of Salt Tolerant Varieties of Paddy in Sodic Soil," Sep. 10, 2018, Excellent Publishers. doi: 10.20546/ijcmas.2018.709.139.
- [14] M. Chen et al., "Adaptation Mechanism of Salt Excluders under Saline Conditions and Its Applications," *International Journal of Molecular Sciences*, vol. 19, no. 11. Multidisciplinary Digital Publishing Institute, p. 3668, Nov. 20, 2018. doi: 10.3390/ijms19113668.
- [15] S. J. Roy, S. Negrão, and M. Tester, "Salt resistant crop plants," *Current Opinion in Biotechnology*, vol. 26. Elsevier BV, p. 115, Jan. 09, 2014. doi: 10.1016/j.copbio.2013.12.004.
- [16] F. Xiao and H. Zhou, "Plant salt response: Perception, signaling, and tolerance," *Frontiers in Plant Science*, vol. 13. Frontiers Media, Jan. 06, 2023. doi: 10.3389/fpls.2022.1053699.
- [17] J. Kearl et al., "Salt-Tolerant Halophyte Rhizosphere Bacteria Stimulate Growth of Alfalfa in Salty Soil," Aug. 14, 2019, Frontiers Media. doi: 10.3389/fmicb.2019.01849.