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Reducing Soil Salinity In Cotton Cultivation Through Biofertilizers

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Abstract: Soil salinity is one of the most persistent constraints affecting cotton productivity in arid and semi-arid regions, particularly under irrigated agricultural systems. Excessive accumulation of soluble salts in the root zone disrupts soil structure, limits water and nutrient uptake, and weakens plant physiological processes, ultimately leading to significant yield reductions. In recent years, biofertilizers have gained increasing attention as an environmentally sustainable alternative to conventional chemical inputs for salinity management. This article provides an in-depth analytical review of the role of biofertilizers in reducing soil salinity in cotton cultivation. Special emphasis is placed on the biological mechanisms through which beneficial microorganisms improve soil aggregation, regulate sodium toxicity, enhance rhizosphere activity, and strengthen plant tolerance to salinity stress. Furthermore, the synergistic effects of biofertilizers when combined with organic amendments and modern irrigation practices are critically examined. The analysis demonstrates that biofertilizer-based approaches not only contribute to the gradual desalinization of soils but also promote long-term soil fertility, ecological stability, and sustainable cotton production.

Keywords: Soil salinity; cotton cultivation; biofertilizers; rhizosphere microorganisms; sustainable agriculture; saline soils; plant stress tolerance; irrigation management.

Introduction: Soil salinity is widely acknowledged as one of the most critical constraints to sustainable cotton production in arid and semi-arid regions, particularly under conditions of intensive irrigation. In Uzbekistan, where cotton cultivation plays a strategically important role in national economic development, export potential, and rural employment, the problem of secondary soil salinization remains highly relevant. Long-term irrigation practices, insufficient drainage, and excessive reliance on mineral fertilizers have resulted in the degradation of soil structure and fertility, thereby threatening the sustainability of cotton-based agroecosystems.

Recognizing the severity of these challenges, Presidential Decrees and resolutions have been adopted which aim at improving land reclamation, ensuring efficient use of land and water resources, and promoting environmentally sustainable agricultural practices. In particular, Presidential Decree No. DP-5742 dated 17 June 2019 “On measures for efficient use of land and water resources in agriculture” emphasizes the necessity of restoring soil fertility on irrigated lands, reducing degradation processes, and introducing resource-saving technologies in crop production. This decree provides a direct policy foundation for the application of biological approaches to soil improvement, including the use of biofertilizers [1].

Furthermore, the long-term policy framework for agricultural modernization is outlined in the Presidential Decree dated 23 October 2019 “On approval of the Agriculture Development Strategy of the Republic of Uzbekistan for 2020–2030.” This strategic document prioritizes sustainable land management, reduction of chemical inputs, and the adoption of innovative agrobiotechnologies. Notably, the strategy highlights the importance of improving soil health through environmentally safe methods, thereby reinforcing the relevance of biofertilizers as a key component of modern cotton cultivation systems [2].

In addition, recent reforms aimed at deepening structural changes in agriculture further strengthen this policy direction. Presidential Decree No. UP-205 dated 12 December 2023 “On additional measures for further development of market relations in agriculture" underscores the need to enhance productivity while maintaining ecological balance. Within this framework, biological soil fertility management tools are increasingly viewed as economically viable and environmentally responsible solutions [3]. Moreover, Presidential Resolution No. PR-71 dated 13 February 2024 focuses on improving the use and protection of agricultural lands, including measures to enhance soil fertility and mitigate salinization processes through advanced agrotechnical and biological interventions [4].

Thus, the growing emphasis on sustainable agriculture at the state level clearly aligns with global trends in climate-resilient farming and ecological intensification. In this context, the introduction of biofertilizers into cotton production systems represents not only a scientifically justified agronomic practice but also a practical implementation of national agricultural policy objectives. Against this background, the present article provides a comprehensive analytical review of the role of biofertilizers in reducing soil salinity in cotton cultivation, examining their biological mechanisms, agronomic effectiveness, and relevance to the strategic priorities set forth in the Presidential Decrees of the Republic of Uzbekistan.

To fully understand the role of biofertilizers, it is essential to consider the complex nature of soil salinity. Salinity develops primarily through the accumulation of soluble salts such as sodium chloride and sodium sulfate in the root zone. As a result, soil osmotic potential increases, making water uptake by cotton plants energetically unfavorable. In addition, sodium ions displace calcium and magnesium from soil colloids, leading to soil dispersion, reduced permeability, and surface crusting. Consequently, root respiration is inhibited, nutrient uptake becomes unbalanced, and microbial activity declines sharply. Thus, salinity is not merely a chemical issue but a combined physical, biological, and physiological stress factor.

Traditionally, soil salinity has been managed through leaching, gypsum application, and improved drainage systems. Although these methods can be effective in the short term, they require substantial water resources and financial investment. Furthermore, excessive leaching often leads to nutrient loss and groundwater contamination. Likewise, chemical amendments may temporarily improve soil structure but fail to restore biological activity. Therefore, while conventional methods remain relevant, they are insufficient on their own to ensure sustainable cotton cultivation under saline conditions [6].

Biofertilizers consist of beneficial microorganisms that enhance soil fertility by biological rather than chemical means. Importantly, these microorganisms do not add salts to the soil; instead, they promote nutrient mobilization, improve soil structure, and enhance plant stress tolerance. From a functional perspective, biofertilizers act as biological regulators of the soil–plant system. Consequently, their application aligns well with the principles of sustainable and climate-resilient agriculture.

Firstly, biofertilizers enhance microbial biomass and activity, which accelerates organic matter decomposition and humus formation. As a result, stable soil aggregates develop, improving porosity and infiltration capacity. Consequently, excess salts are more easily leached from the upper soil layers to deeper horizons, where they pose less risk to cotton roots. Over time, this biological aggregation process contributes to the gradual desalinization of the root zone.

Secondly, certain microorganisms produce organic acids and chelating compounds that interact with sodium ions. Through these biochemical processes, sodium is either immobilized or displaced from exchange sites. Meanwhile, calcium availability increases, restoring the soil's cation balance. Therefore, soil sodicity decreases, and structural stability improves. This mechanism is particularly important in saline–sodic soils, where sodium toxicity is a major constraint.

In addition to modifying soil properties, biofertilizers directly influence cotton plant physiology. Plant growth-promoting microorganisms synthesize phytohormones, osmoprotectants, and antioxidants. Consequently, cotton plants exhibit improved root growth, enhanced chlorophyll content, and better water-use efficiency. Moreover, the production of stress-related enzymes enables plants to maintain metabolic activity even under high salt concentrations. Thus, biofertilizers not only reduce salinity effects but also strengthen plant adaptive capacity [5].

Equally important is the role of biofertilizers in reshaping the rhizosphere environment. The rhizosphere serves as the interface between soil and plant roots, where nutrient exchange and microbial interactions occur. By colonizing this zone, beneficial microorganisms suppress pathogenic species and create a biologically active microenvironment. Consequently, nutrient uptake efficiency increases, while salinity-induced root damage is minimized. In this way, the rhizosphere becomes a buffer zone that protects cotton plants from external stress.

Furthermore, the effectiveness of biofertilizers is significantly enhanced when combined with organic amendments such as compost or farmyard manure. Organic matter serves as both a carbon source for microorganisms and a structural improver for saline soils. As organic carbon increases, cation exchange capacity improves, allowing soils to retain essential nutrients while releasing excess sodium. Therefore, the combined application creates a synergistic effect that accelerates soil rehabilitation.

Another critical factor is the integration of biofertilizers with modern irrigation techniques. Drip irrigation, in particular, allows precise placement of microbial inoculants in the root zone. Consequently, microbial survival and activity increase, while water application remains controlled. At the same time, localized leaching of salts occurs without excessive water use. Thus, irrigation management and biofertilizer application must be considered complementary rather than independent practices.

From an agronomic perspective, the use of biofertilizers leads to improved plant vigor, higher boll retention, and enhanced fiber quality. Economically, reduced dependence on chemical fertilizers lowers production costs over time. Environmentally, improved soil biological activity contributes to carbon sequestration and reduces pollution risks. Therefore, biofertilizers offer a holistic solution that addresses productivity, profitability, and sustainability simultaneously.

CONCLUSION

In summary, biofertilizers represent a scientifically sound and ecologically sustainable approach to reducing soil salinity in cotton cultivation. Through improvements in soil structure, ionic balance, rhizosphere health, and plant physiological resilience, they address the problem of salinity in a comprehensive manner. Therefore, when integrated with organic amendments and efficient irrigation practices, biofertilizers can significantly contribute to the long-term sustainability of cotton-based agroecosystems.

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