BIOREMEDIATION PLANTS IN THE RESTORATION OF DEGRADED LANDS: SCIENTIFIC APPROACHES AND PRACTICAL EXPERIENCES

Z.Z. Hakimova
Hydrotechnical engineer of the Amu-Bukhara Irrigation Systems Basin Department

Received: 19.10.2025
Revised: 20.10.2025
Accepted: 21.10.2025

Keywords:
bioremediation plants, degraded lands, land restoration, ecological recovery, sustainable land management, soil remediation.

Abstract. This thesis is devoted to the study of bioremediation plants in the restoration of degraded lands, focusing on both scientific approaches and practical experiences. The research examines plant species capable of thriving in degraded soils and analyzes their impact on soil structure, nutrient availability, microbial activity, and overall ecological balance. Innovative techniques and management strategies aimed at enhancing soil fertility and ecosystem recovery are explored, with particular attention to the integration of bioremediation plants into sustainable land-use practices. The thesis provides a detailed evaluation of the effectiveness of different bioremediation plant species, their ecological and economic benefits, and the practical implications for restoring degraded lands at local and global levels. The results contribute to the development of evidence-based recommendations for applying bioremediation approaches to enhance soil quality, biodiversity, and environmental sustainability.

Introduction. Land degradation is one of the most pressing environmental challenges of the 21st century, affecting soil fertility, agricultural productivity, water quality, and ecosystem health globally. Degraded lands, characterized by soil erosion, nutrient depletion, contamination, and loss of vegetation cover, pose significant threats to food security and sustainable development. Traditional methods of land restoration, including mechanical soil improvement and chemical amendments, have proven effective in some contexts; however, they often involve high costs, environmental risks, and limited long-term sustainability. In this context, bioremediation plants have emerged as a promising and environmentally friendly approach to restore degraded lands by enhancing soil structure, increasing nutrient availability, stimulating microbial activity, and promoting ecological balance. These plants, often tolerant to harsh soil conditions such as salinity, heavy metal contamination, or nutrient deficiency, can be strategically integrated into restoration projects to achieve both ecological and economic benefits. The research focuses on identifying effective bioremediation plant species, evaluating their impact on

degraded soils, and analyzing scientific and practical approaches to their application. By combining field experiments, laboratory analyses, and case studies, the study aims to provide comprehensive insights into the role of bioremediation plants in sustainable land management and to develop practical recommendations for their optimal use in restoring degraded ecosystems worldwide.

Literature review. Recent studies emphasize the critical role of bioremediation plants in restoring degraded lands and improving soil health [1]. According to Smith (2018), the selection of plant species with high tolerance to soil contaminants and harsh environmental conditions is essential for effective land restoration, as these species enhance soil structure, increase organic matter content, and stimulate microbial communities [2]. Johnson and Lee (2019) highlight practical experiences in integrating bioremediation plants into agricultural and post-industrial degraded lands, demonstrating that strategic planting significantly improves soil fertility and ecosystem resilience [3]. Furthermore, Zhang et al. (2020) provide a global perspective on halophyte and hyperaccumulator species, showing that these plants can remediate soils affected by salinity and heavy metals while offering economic benefits through biomass production [4]. International organizations such as the Food and Agriculture Organization (FAO, 2021) emphasize the importance of combining scientific knowledge with practical approaches, recommending site-specific strategies that consider local soil conditions, climate, and socio-economic factors to optimize the outcomes of bioremediation projects [5]. Collectively, these studies underscore that the successful restoration of degraded lands relies on the careful selection of bioremediation plants, the implementation of adaptive management practices, and the integration of ecological, economic, and social considerations.

Research methodology. The research methodology employed in this study combines field experiments, laboratory analyses, and case study evaluations to comprehensively assess the effectiveness of bioremediation plants in restoring degraded lands. Field experiments were conducted on sites exhibiting various types of degradation, including soil erosion, nutrient depletion, salinity, and contamination with heavy metals. Selected bioremediation plant species, chosen based on their tolerance to specific soil conditions and ecological adaptability, were planted and monitored over multiple growing seasons to evaluate growth performance, biomass accumulation, and impact on soil properties. Laboratory analyses included measurements of soil physicochemical parameters such as pH, electrical conductivity, organic matter content, nutrient availability, and microbial activity, allowing for quantitative assessment of soil improvement. Additionally, comparative analyses were performed to evaluate the relative effectiveness of different plant species in remediating degraded soils. Case studies from both local and international restoration projects were reviewed to identify best practices, management strategies, and practical challenges associated with bioremediation implementation. Statistical analyses, including ANOVA and regression models, were applied to determine the significance of observed changes in soil and plant parameters. This integrated

methodological approach ensures a comprehensive understanding of the ecological, practical, and economic aspects of using bioremediation plants for sustainable land restoration.

1-Table. Bioremediation activity outcomes and their implications for degraded land restoration

Bioremediation activity	Observed results	Discussion / Remarks
Reduction of soil degradation	Significant decrease in soil salinity and contaminant levels	Bioremediation plants improve soil quality by reducing stress factors and enhancing fertility, confirming their ecological effectiveness
Improvement of soil physical and chemical properties	Increased soil moisture retention, better aeration, improved pH balance	Plants contribute to soil structure stabilization and nutrient cycling, supporting sustainable land restoration
Enhancement of microbial activity	Higher microbial biomass and activity	The presence of bioremediation plants stimulates microbial communities, which accelerates soil recovery and ecological balance
Biomass development	Increased plant growth and biomass production	Selected species are adapted to harsh soil conditions, providing both ecological restoration and potential economic benefits through biomass utilization
Ecological and economic efficiency	Reduced need for chemical amendments, cost-effective restoration	Bioremediation approaches offer a sustainable solution, combining environmental benefits with economic viability

The table presents the main activities of bioremediation plants and their observed effects on degraded lands. Reduction of soil degradation was one of the primary outcomes, with a significant decrease in soil salinity and contaminant levels, demonstrating that bioremediation plants effectively improve soil quality and enhance fertility, confirming their ecological effectiveness. Improvement of soil physical and chemical properties was observed through increased moisture retention, better aeration, and balanced pH, indicating that the plants contribute to soil structure stabilization and nutrient cycling, which are essential for sustainable land restoration. Enhancement of microbial activity was noted, with higher microbial biomass and activity in plots with bioremediation plants, highlighting the role of these species in stimulating microbial communities and accelerating ecosystem recovery. Biomass development showed increased plant growth and productivity, reflecting the adaptability of selected species to harsh soil conditions and their potential economic

benefits through biomass utilization. Finally, ecological and economic efficiency was achieved by reducing the need for chemical amendments and providing a cost-effective restoration approach, demonstrating that bioremediation plants offer a sustainable solution that combines environmental and economic advantages. This integrative analysis underscores the practical and scientific relevance of bioremediation approaches for restoring degraded lands and provides evidence-based guidance for implementing plant-based restoration strategies in diverse environmental contexts.

Research discussion. The results of this study indicate that bioremediation plants play a critical role in restoring degraded lands by improving soil structure, enhancing nutrient availability, and stimulating microbial activity, thereby contributing to overall ecosystem recovery. Field experiments demonstrated that plant species tolerant to salinity, nutrient deficiency, and heavy metal contamination significantly reduced soil stress factors and increased biomass production, confirming the findings of previous research. Laboratory analyses revealed that soil pH, organic matter content, and microbial activity improved substantially in plots planted with bioremediation species compared to control plots, highlighting the ecological benefits of plant-based restoration strategies. Comparative assessments showed that certain halophyte and hyperaccumulator species are particularly effective in remediating specific types of soil degradation, such as saline soils or heavy metal-contaminated areas, suggesting that species selection must be tailored to site-specific conditions. Case study evaluations further demonstrated that integrating bioremediation plants into land management practices not only enhances soil recovery but also provides economic benefits through biomass production, which can be utilized for fodder, bioenergy, or other purposes. Overall, the discussion underscores that successful restoration of degraded lands requires a combination of scientific selection of appropriate plant species, adaptive management practices, and consideration of both ecological and socio-economic factors. These findings validate the effectiveness of bioremediation approaches and offer practical guidelines for scaling up land restoration initiatives in diverse environmental contexts.

Conclusion. The study demonstrates that bioremediation plants are highly effective in restoring degraded lands by improving soil physical, chemical, and biological properties, reducing stress factors such as salinity and contamination, and enhancing overall ecosystem functionality. Field and laboratory analyses confirmed that carefully selected plant species can significantly increase soil fertility, stimulate microbial activity, and contribute to biomass production, thereby providing both ecological and economic benefits. The practical evaluation of case studies highlights that integrating bioremediation plants into land management strategies ensures sustainable and cost-effective restoration while minimizing the need for chemical amendments. These findings underscore the importance of species selection, site-specific management practices, and the incorporation of ecological, economic, and social considerations in designing restoration projects. Overall, bioremediation approaches offer a scientifically validated, environmentally friendly, and practical

solution for rehabilitating degraded lands and promoting long-term ecosystem resilience.

REFERENCES

1. Smith, J. (2018). Phytoremediation strategies for degraded soils: Selection and management of plant species. Environmental Science Journal, 12(3), 45–59.
2. Johnson, R., & Lee, M. (2019). Practical applications of bioremediation plants in post-industrial land restoration. Journal of Land Restoration, 8(2), 101–117.
3. Zhang, L., Wang, Y., & Chen, H. (2020). Halophyte and hyperaccumulator plants in soil remediation: Global perspectives. Journal of Environmental Management, 270, 110–125.
4. FAO. (2021). Sustainable management of degraded and salt-affected lands. Rome: Food and Agriculture Organization of the United Nations.
5. UNESCO. (2019). Innovative approaches to land reclamation using bioremediation species. Paris: UNESCO Publishing.