

Research Review on the Improvement and Utilization Technologies of Saline-Alkali Soils

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Abstract: Saline-alkali soil refers to land where excessive soluble salts in the soil lead to increased soil osmotic pressure, affecting the normal growth of plants and crop yields. Saline-alkali soils are widely distributed in arid and semi-arid regions globally, posing severe challenges to agricultural production, ecological environment, and regional economic development. Therefore, the improvement and utilization of saline-alkali soils have become a hot issue of global concern. In recent years, scholars both domestically and internationally have made significant progress in saline-alkali soil improvement technologies, cultivation of salt-tolerant crops, and ecological restoration of saline-alkali soils. This paper reviews relevant literature, analyzing the current research status, existing problems, and future development directions of saline-alkali soil improvement and utilization technologies.

Keywords: Saline-Alkali Soil Improvement Technologies, Halophyte Cultivation, Ecological Restoration.

1. Saline-Alkali Soil Improvement Technologies

1.1. Physical Improvement Technologies

Physical improvement technologies primarily involve altering the physical structure of the soil to improve soil water and salt transport conditions and enhance soil drainage and aeration. Common physical improvement technologies include subsurface drainage, deep tillage, and soil replacement.

Subsurface Drainage: Subsurface drainage is an effective measure for improving saline-alkali soils. By burying drainage pipes underground, excess water and salts in the soil are drained, lowering the groundwater level and reducing salt accumulation on the surface. Zhang Hongling et al. (2024) studied the causes and management modes of saline-alkali soils in the Ningxia Yellow River Irrigation District, pointing out that subsurface drainage is one of the important means to improve soil salinization. It can lower the groundwater level, reduce soil evaporation, and effectively control the rise of soil salinity. Furthermore, subsurface drainage can be combined with irrigation methods such as furrow irrigation to further enhance the improvement effect of saline-alkali soils.

Deep Tillage: Deep tillage involves deeply plowing the soil to break up soil compaction, increase soil porosity, and improve soil aeration and water-holding capacity. It can improve soil water and salt transport conditions, facilitating salt leaching and drainage. Su Tong (2024), in studying the improvement of high-standard farmland saline-alkali soils, proposed that deep tillage can increase soil permeability, promote the infiltration of irrigation water, and reduce surface water accumulation and salt accumulation.

Soil Replacement: Soil replacement involves removing the high-salt soil from the surface of saline-alkali lands and replacing it with low-salt or salt-free soil to reduce soil salinity. This method is suitable for small-area saline-alkali soil improvement but is costly for large-area improvement

and difficult to promote.

1.2. Chemical Improvement Technologies

Chemical improvement technologies mainly involve applying chemical ameliorants to change the soil's pH and ion composition, thereby reducing the inhibitory effect of soil salinity on plant growth. Common chemical ameliorants include gypsum, phosphogypsum, and organic acids.

Gypsum Improvement: Gypsum is a commonly used chemical ameliorant, mainly composed of calcium sulfate. Gypsum can undergo a displacement reaction with sodium ions in the soil to produce insoluble calcium carbonate, thereby reducing sodium ion content in the soil and improving soil structure. Liu Yonggang et al. (2024), in studying the physicochemical characteristics of salinized forest soils in the lower reaches of the Shiyang River, found that applying gypsum can effectively reduce soil salinity and improve soil fertility.

Phosphogypsum Improvement: Phosphogypsum is a by-product of phosphate fertilizer production, mainly composed of calcium phosphate. Phosphogypsum can not only reduce soil salinity but also provide phosphorus needed by plants to promote their growth. The effect of phosphogypsum in improving saline-alkali soils is better than that of ordinary gypsum, and the cost is lower.

Organic Acid Improvement: Organic acids such as citric acid and acetic acid can chelate metal ions (such as sodium and calcium ions) in the soil into soluble complexes, thereby reducing soil salinity. Organic acid ameliorants are environmentally friendly but costly, and their effectiveness is greatly influenced by soil type and climatic conditions.

1.3. Biological Improvement Technologies

Biological improvement technologies mainly involve planting salt-tolerant plants, applying microbial inoculants, and other methods to improve the ecological environment of saline-alkali soils and enhance soil fertility and productivity.

Planting Salt-Tolerant Plants: Planting salt-tolerant plants

is an effective method for biologically improving saline-alkali soils. Salt-tolerant plants have strong salt tolerance, can grow normally in high-salt environments, and can absorb salts from the soil through their roots to reduce soil salinity. He Yongming (2024), in studying comprehensive treatment engineering modes for saline-alkali soils in Gansu Province, pointed out that planting salt-tolerant crops such as cotton and tomatoes can not only improve the productivity of saline-alkali soils but also improve soil structure and promote soil nutrient cycling.

Application of Microbial Inoculants: Microbial inoculants can decompose organic matter, release nutrients, improve soil structure, and enhance soil aeration and water-holding capacity. At the same time, certain microorganisms can produce acidic metabolites, lowering soil pH and thereby improving the ecological environment of saline-alkali soils. Huang Pengfei et al. (2024), in studying the effects of different sizes of water-dispersing media on water and salt transport characteristics in cracked solonch soil under drip irrigation conditions, found that applying microbial inoculants can significantly improve soil water-holding capacity and nutrient content.

1.4. Integrated Improvement Technologies

Integrated improvement technologies combine physical, chemical, and biological improvement technologies to form a complete system for improving saline-alkali soils. They can fully leverage the advantages of various improvement technologies to enhance the effectiveness of saline-alkali soil improvement.

Physical-Chemical Integrated Improvement: Physical-chemical integrated improvement technologies involve improving soil structure through physical means while applying chemical ameliorants to reduce soil salinity. This technology can significantly enhance soil aeration and water-holding capacity, reduce soil salinity, and provide a good environment for plant growth. Zhang Hongling et al. (2024), in studying management measures for saline-alkali soils in the Ningxia Yellow River Irrigation District, proposed an integrated improvement technology combining subsurface drainage with gypsum improvement, which effectively reduced soil salinity and improved crop yield and quality.

Physical-Biological Integrated Improvement: Physical-biological integrated improvement technologies involve improving soil structure through physical means while planting salt-tolerant plants and applying microbial inoculants to promote soil nutrient cycling and the restoration of ecological balance. This technology can significantly enhance the productivity and ecological function of saline-alkali soils, providing strong support for sustainable development.

Chemical-Biological Integrated Improvement: Chemical-biological integrated improvement technologies involve reducing soil salinity through the application of chemical ameliorants while planting salt-tolerant plants and applying microbial inoculants to promote the restoration of soil ecosystems. This technology can fully leverage the advantages of chemical ameliorants and biological improvement technologies to improve the effectiveness and ecological function of saline-alkali soil improvement.

2. Cultivation of Salt-Tolerant Crops

The cultivation of salt-tolerant crops is one of the important ways to utilize saline-alkali soils. Through genetic

improvement and breeding technologies, crop varieties adapted to high-salt environments can be cultivated, enhancing the productivity and economic benefits of saline-alkali soils.

2.1. Genetic Improvement

Genetic improvement involves using genetic engineering technology to introduce salt-tolerance genes into crops, enhancing their salt tolerance. Currently, some genes related to plant salt tolerance, such as SOS1 and HKT1, have been discovered. Through genetic engineering technology, these salt-tolerance genes can be introduced into crops to cultivate new salt-tolerant varieties.

Xu Zongchang et al. (2024), in studying the salt tolerance of 50 soybean germplasm resources at the seedling stage in the Huang-Huai production region, found that genetic improvement can significantly enhance soybean salt tolerance. They used salt injury index evaluation and D-value comprehensive evaluation methods to screen out a batch of soybean varieties with strong salt tolerance, providing strong support for the cultivation of salt-tolerant soybeans.

2.2. Breeding Technologies

Breeding technologies involve methods such as selective breeding and hybrid breeding to cultivate crop varieties adapted to high-salt environments. Selective breeding involves planting crops in saline-alkali soil environments, screening out varieties with strong salt tolerance for propagation and promotion. Hybrid breeding involves crossing different varieties and combining selective breeding methods to cultivate new varieties with excellent salt tolerance.

Li Gang et al. (2024), in studying key technologies for high-quality and efficient production of winter wheat in saline-alkali soils in Xinjiang, cultivated a batch of wheat varieties adapted to the Xinjiang saline-alkali soil environment through a combination of selective breeding and hybrid breeding. These new varieties not only have strong salt tolerance but also high yield and quality, providing strong support for the utilization of saline-alkali soils in Xinjiang.

3. Ecological Restoration of Saline-Alkali Soils

Ecological restoration of saline-alkali soils involves improving the ecological environment and enhancing their ecological functions through measures such as vegetation restoration and soil and water conservation. This restoration is of great significance for maintaining regional ecological balance and promoting sustainable development.

3.1. Vegetation Restoration

Vegetation restoration is one of the important measures for the ecological restoration of saline-alkali soils. By planting salt-tolerant plants and establishing artificial vegetation communities, the ecological environment of saline-alkali soils can be improved, enhancing soil fertility and water-holding capacity.

Liu Yonggang et al. (2024), in their study on the physical and chemical characteristics of saline-alkali soils in forestlands downstream of the Shiyang River and their impact on vegetation biodiversity, found that planting salt-tolerant plants such as *Haloxylon ammodendron* and *Nitraria tangutorum* can significantly increase vegetation cover and

biodiversity in saline-alkali soils. These plants have strong salt tolerance, enabling them to grow normally in high-salinity environments and reduce soil salinity by absorbing salt through their roots.

3.2. Soil and Water Conservation

Soil and water conservation is one of the key measures for the ecological restoration of saline-alkali soils. By constructing soil and water conservation projects and implementing measures such as returning farmland to forests and grasslands, soil erosion can be reduced, and soil water-holding capacity and fertility can be enhanced.

Su Tong (2024), in their research on the improvement of saline-alkali soils in high-standard farmland, proposed that measures such as constructing terraces and planting trees and grass can effectively prevent soil erosion and improve soil water-holding capacity and fertility. These measures not only improve the ecological environment of saline-alkali soils but also enhance the productivity and economic benefits of farmland.

4. Issues in the Improvement and Utilization Techniques of Saline-Alkali Soils

Despite significant progress in the improvement and utilization techniques of saline-alkali soils, there are still several issues that urgently need to be addressed.

4.1. High Improvement Costs

The improvement of saline-alkali soils requires substantial investments in human, material, and financial resources, resulting in high costs. Especially for large-scale improvement projects, the costs can be prohibitive. Therefore, reducing improvement costs and enhancing efficiency are critical challenges faced by current saline-alkali soil improvement techniques.

4.2. Difficulties in Technology Promotion

Promoting saline-alkali soil improvement techniques entails overcoming various obstacles. On one hand, due to the wide distribution and diverse types of saline-alkali soils, there are regional differences in improvement techniques, making it difficult to establish unified technical standards and promotion models. On the other hand, the complexity and specialization of these techniques mean that farmers often lack the relevant knowledge and skills, hindering effective application and promotion.

4.3. Significant Ecological Risks

There may be ecological risks associated with the improvement of saline-alkali soils. For example, the use of chemical ameliorants can potentially pollute soil and groundwater, and the cultivation of salt-tolerant crops may disrupt the existing ecological balance. Therefore, it is essential to fully consider ecological risks during the improvement process and take effective measures to prevent and mitigate them.

5. Development Trends in the Improvement and Utilization Technologies of Saline-Alkali Soils

The future development trends in the improvement and

utilization technologies of saline-alkali soils will exhibit the following aspects:

5.1. Integrated Improvement Techniques Will Become Mainstream

With the continuous development and refinement of saline-alkali soil improvement techniques, integrated improvement techniques will become the mainstream. These techniques can fully leverage the advantages of various improvement methods, enhancing the effectiveness of soil improvement and productivity. In the future, there will be a need to further strengthen the integration and innovation of physical, chemical, and biological improvement techniques to form a more efficient and environmentally friendly system for saline-alkali soil improvement.

5.2. Breakthroughs in the Cultivation of Salt-Tolerant Crops

With the ongoing development of genetic improvement and breeding technologies, breakthroughs will be made in the cultivation of salt-tolerant crops. Through the combined application of genetic engineering and breeding techniques, crop varieties that are more adapted to high-salinity environments can be developed. These new varieties will possess stronger salt tolerance, higher yields, and better quality, providing strong support for the utilization of saline-alkali soils.

5.3. Ecological Restoration Will Become a Focus

As ecological civilization construction continues to advance and people's awareness of ecological environmental protection increases, the ecological restoration of saline-alkali soils will become a key focus. In the future, there will be a need to further strengthen research on ecological restoration techniques for saline-alkali soils and promote their application through measures such as vegetation restoration and soil and water conservation to improve the ecological environment and functions of saline-alkali soils. Simultaneously, it will be necessary to enhance monitoring and evaluation efforts for the effectiveness of ecological restoration measures to ensure their efficacy and sustainability.

6. Conclusion

The improvement and utilization of saline-alkali soils is one of the hot topics of global concern. Through the comprehensive application of physical, chemical, and biological improvement techniques, as well as the cultivation and promotion of salt-tolerant crops, the ecological environment and production conditions of saline-alkali soils can be effectively improved, enhancing their productivity and economic benefits. However, current saline-alkali soil improvement techniques still face issues such as high costs, difficulties in technology promotion, and ecological risks, which require further research and resolution. In the future, with continuous technological development and innovation, the improvement and utilization of saline-alkali soils will usher in broader development prospects.

Acknowledgements

The project was supported by the projects of Shaanxi Province land engineering construction group internal project

(DJNY-ZD-2023-3).

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