

SUSTAINABLE REMEDIATION STRATEGIES FOR SALINE SOILS IN NINGXIA CHINA: A  
REVIEW OF METHODS AND PRACTICES

A Thesis

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## ABSTRACT

This review explores sustainable remediation strategies for saline soils in Ningxia, China, where excessive agricultural water use and an arid climate have exacerbated soil degradation. Key strategies include biochar application to enhance soil structure and nutrient cycling, organic amendments like straw interlayers to boost soil organic carbon and microbial activity, and controlled drip irrigation for effective soil rehabilitation. The review also advocates for an integrated ecosystem approach that promotes biodiversity and addresses the limitations of single-species strategies. Climate-adaptive techniques are emphasized as essential to counter increasing soil salinization due to climate change. Despite the promise of these methods, challenges such as high costs and the need for widespread adoption by local farmers persist. The review calls for optimized, locally tailored solutions that integrate water and soil management practices, aiming to reclaim saline soils and enhance agricultural sustainability in Ningxia and similar regions globally.

## BIOGRAPHICAL SKETCH

Ruitao Li, born in Yinchuan, Ningxia, China, holds a Bachelor's degree in Environmental Science. He has served as an assistant researcher at the National Key Laboratory of Seedling Bioengineering at the Ningxia Forestry Research Institute. Ruitao Li's research focuses on desertification control, phytoremediation, removal of pollutants from water, and biochar. He has accumulated extensive practical experience in these areas and has a deep interest in improving the ecological environment and contributing to sustainable development.

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## **Introduction**

Soil salinization is a critical global issue affecting over 900 million hectares of agricultural land worldwide, representing more than 6% of the world's total area (Xie et al., 2017). In Ningxia, China, this problem is particularly acute due to the region's unique climate characteristics and long-term agricultural practices. Ningxia's arid to semi-arid climate, characterized by low precipitation and high evaporation rates, exacerbates the accumulation of salts in the soil profile. This situation is further complicated by the fact that over 90% of Ningxia's water resources were allocated to agriculture in 2023, significantly surpassing China's national average of 65%. This disproportionate water usage is partly attributed to severe soil degradation, which necessitates increased irrigation to maintain crop productivity.

The challenges posed by saline soils in Ningxia are multifaceted, impacting soil physical properties, microbial communities and, ultimately, agricultural productivity. High soil salinity leads to decreased soil organic carbon, hampered soil fertility, and reduced microbial activity, all of which are critical for sustainable agriculture (Xie et al., 2017; Zhao et al., 2017). These issues not only threaten food security, but also contribute to environmental degradation and economic losses. Therefore, developing sustainable remediation strategies for saline soils in Ningxia and elsewhere is of paramount importance to ensure long-term agricultural sustainability and ecological balance in the region.

## **Methods**

To address the complex issue of soil salinization in Ningxia and develop sustainable remediation strategies, a comprehensive approach combining literature review, data analysis, and stakeholder engagement was employed. The methods used in this study are as follows:

### **1. Literature Review and Data Collection:**

A thorough review of scientific literature, government reports, and local agricultural documents was conducted to gather information on soil salinization in Ningxia and potential remediation strategies. This included studies on soil properties, climate data, agricultural practices, and water management in the

region. Special attention was given to research on biochar application, organic amendments, and innovative irrigation techniques, which have shown promise in ameliorating saline soils (Saifullah et al., 2018; Yuan et al., 2023).

## 2. Analysis of Climate and Agricultural Data:

Climate data specific to Ningxia were analyzed to understand the regional characteristics that contribute to soil salinization. This included examining precipitation patterns, evapotranspiration rates, and temperature trends. Agricultural data, particularly water usage statistics and crop production figures, were also analyzed to assess the impact of current practices on soil health and water resources.

## 3. Stakeholder Interviews:

Semi-structured interviews were conducted with local agricultural experts, soil scientists, farmers, and government officials involved in land management. These interviews provided valuable insights into the historical context of land degradation in Ningxia, current challenges, and ongoing efforts to address soil salinization. Notably, the interviews revealed that past approaches to soil management and desertification control were often overly simplistic, focusing on single-species vegetation strategies that proved inadequate for long-term soil health.

## 4. Assessment of Current and Emerging Technologies:

Information gathered from interviews and literature was used to evaluate the effectiveness of various soil remediation technologies currently being researched and implemented in Ningxia. This included assessing innovative approaches such as the use of salt-tolerant crops, advanced irrigation systems, and soil amendments tailored to local conditions.

## 5. Synthesis and Recommendations:

Based on the collected data, literature findings, and stakeholder input, a comprehensive analysis was performed to identify the most promising and sustainable remediation strategies for saline soils in

Ningxia. Recommendations were formulated considering the local ecological conditions, economic feasibility, and long-term sustainability of proposed interventions.

This multifaceted approach aimed to provide a holistic understanding of the soil salinization issue in Ningxia and to develop context-specific, sustainable remediation strategies that address both immediate concerns and long-term agricultural sustainability in the region.

## **Results**

### **1. Current State of Soil Salinization in Ningxia:**

Analysis of soil data revealed that a significant portion of Ningxia's agricultural land is affected by salinization, with electrical conductivity (EC<sub>e</sub>) values often exceeding 4 dS/m, the threshold for saline soils (Qadir et al., 2000). This high salinity has led to reduced soil organic carbon (SOC) content and impaired microbial activity, severely affecting soil fertility and crop productivity.

### **2. Climate Impact on Soil Salinity:**

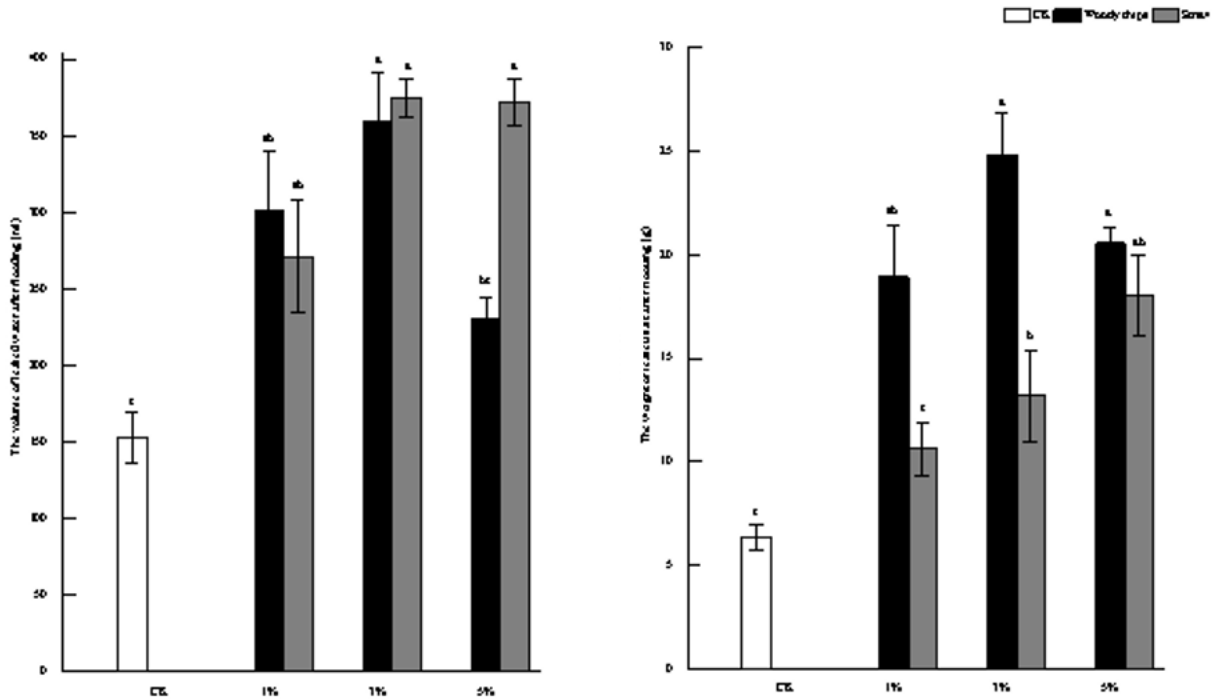
Climate data analysis showed that Ningxia's arid to semi-arid climate, characterized by low annual precipitation (often below 200 mm) and high evapotranspiration rates, significantly contributes to salt accumulation in the soil profile. This aligns with global predictions of increased soil salinization under changing climate conditions (Hassani et al., 2021).

### **3. Water Management and Agricultural Practices:**

Studies have found that over 90% of water resources in Ningxia are used for agriculture, significantly higher than the national average of 65%. This high-water consumption rate is often due to inefficient irrigation methods. In Ningxia, where evaporation rates are already high, this raises the groundwater level, bringing salts to the surface and exacerbating the problem of soil salinization.

#### **3.1 The leaching effect of irrigation on soil salinity:**

Irrigation can carry away some soluble salts from the soil, with sodium ions being the most abundant and toxic salt ions in the saline-alkali soils of Ningxia. Leaching experiments conducted by Huo have shown that the addition of wood chips and straw can increase soil porosity, significantly increasing the volume of collected leachate compared to the control ( $P < 0.05$ ). As the amount of straw added increases, the volume of leachate also increases significantly. However, when the addition of wood chips reaches 3%, the volume of collected leachate is at its maximum, but it decreases when the addition reaches 5%. The addition of wood chips and straw enhances the leaching effect of irrigation on soil salinity. Specifically, when 3% wood chips and straw are added, a single irrigation can leach out 17.8g and 11.6g of sodium ions, respectively, which is 3.92 times and 2.08 times the amount in the control. When 5% wood chips and straw are added, the amount of salt leached out by irrigation is 3.25 times and 2.85 times that of the control, respectively (Figure 1).



**Fig. 1 The drip washing of irrigation on soil salt content**

**Note: the left is the volume of leaked water, the right is the weight of leaked salt**

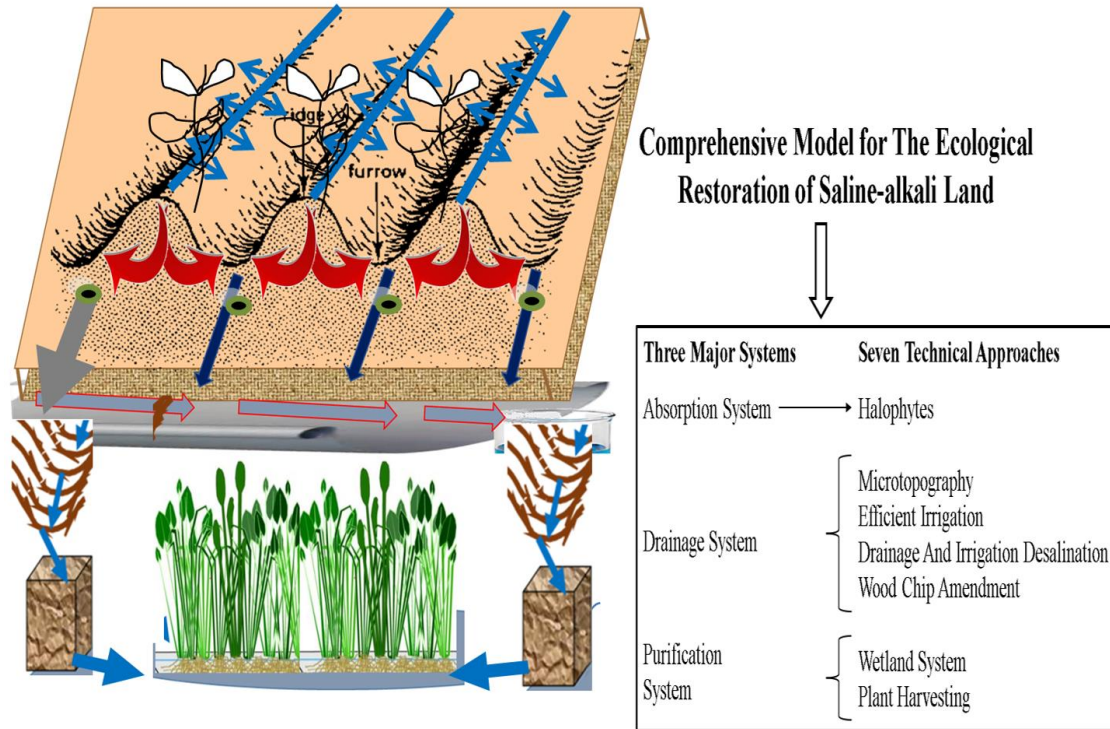
#### 4. Effectiveness of Remediation Strategies:

4.1 Biochar Application: Experiments with biochar derived from agricultural waste showed promising results in improving soil structure, enhancing nutrient cycling, and providing habitats for microorganisms in saline soils (Yuan et al., 2023). Biochar application was found to reduce soil electrical conductivity (EC<sub>e</sub>) and improve water holding capacity.

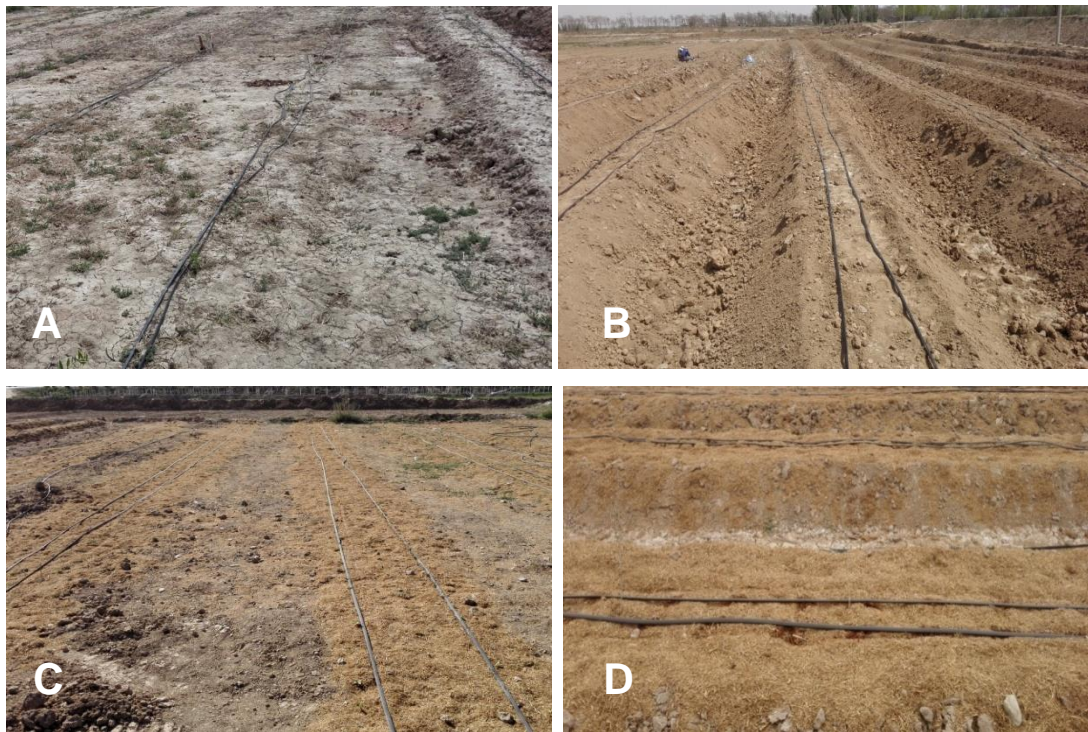
4.2 Organic Amendments: The addition of organic materials, particularly straw, demonstrated significant improvements in soil organic carbon content and microbial activity. A 5 cm thick straw interlayer was found to be particularly effective in improving root growth and altering microbial community composition in favor of beneficial microorganisms (Chen et al., 2024).

4.3 Irrigation Management: Drip irrigation with controlled soil matric potential (SMP) showed effectiveness in rehabilitating saline soils and promoting the growth of salt-tolerant plants. Maintaining an SMP higher than  $-5$  kPa at a 20 cm depth was found to be effective for vegetation rehabilitation (Sun et al., 2012).

4.4 Comprehensive management (Figure 2 and Figure 3): (1) a soil salt absorption system, utilizing halophytes for direct absorption of soil salts through bioremediation; (2) a soil salt drainage and irrigation system, integrating techniques such as adding crushed wood chips, furrow technology, drip irrigation (drainage-based irrigation), no-till techniques, and drainage and irrigation systems to accelerate soil desalination, lower groundwater levels, prevent soil salt accumulation, and discharge leached salts into wetland systems outside the saline-alkali land; (3) a wetland system salt purification system, where salt-tolerant aquatic plants absorb and transfer the salts from the wetland system, and through harvesting the above-ground biomass, the salts are ultimately removed from the wetland system.



**Fig.2 The sketch map of comprehensive restoration pattern of saline-alkali land**



**Fig. 3. The sites of comprehensive restoration pattern of saline-alkali land. A: Control; B: Ridge and furrow; C: Woody chips; D: Ridge furrow + wood chips.**

Ni et al. (in prep) found that soil salinity decreased during irrigation across all treatments. The furrow ridge + wood chips treatment group and the wood chip treatment group exhibited the largest reductions in soil salinity, while the furrow ridge treatment group and the CK (control) group showed smaller reductions. The soil salinity in the CK group was 120%, 116%, and 99% of that in the furrow ridge + wood chip (see note at beginning please) treatment group, the wood chips treatment group, and the furrow ridge treatment group, respectively. Therefore, the remediation techniques used in the furrow ridge + wood chips treatment group and the wood chips treatment group can enhance the soil's water retention capacity and reduce soil salinity. During irrigation, all treatments saw a reduction in soil salinity, with the furrow ridge + wood chips treatment group and the wood chips treatment group showing the greatest decreases. In contrast, the furrow ridge treatment group and the CK group had smaller reductions. The soil salinity in the CK group was 120%, 116%, and 99% of that in the furrow ridge + wood chips treatment group, the wood chips treatment group, and the furrow ridge treatment group, respectively. Thus, the remediation techniques in the furrow ridge + wood chips treatment group and the wood chips treatment group can enhance soil water retention and reduce soil salinity (Figure 4 and Figure 5). This conclusion is consistent with the experimental results reported by Liu et al. (2013).

I Spatial and temporal variability of soil salinity in 2017 (ds/m)

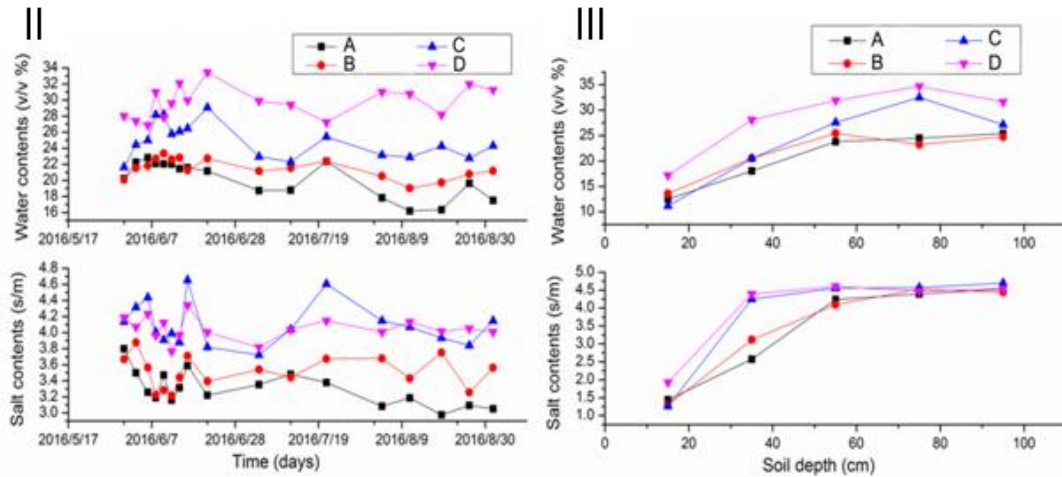
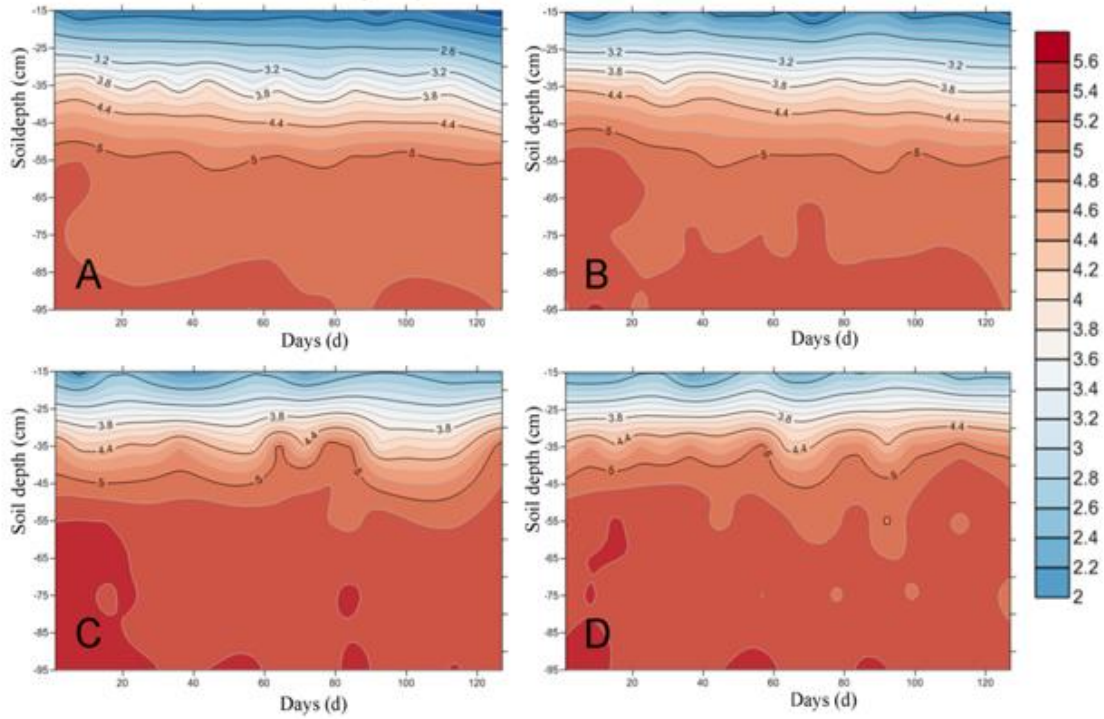
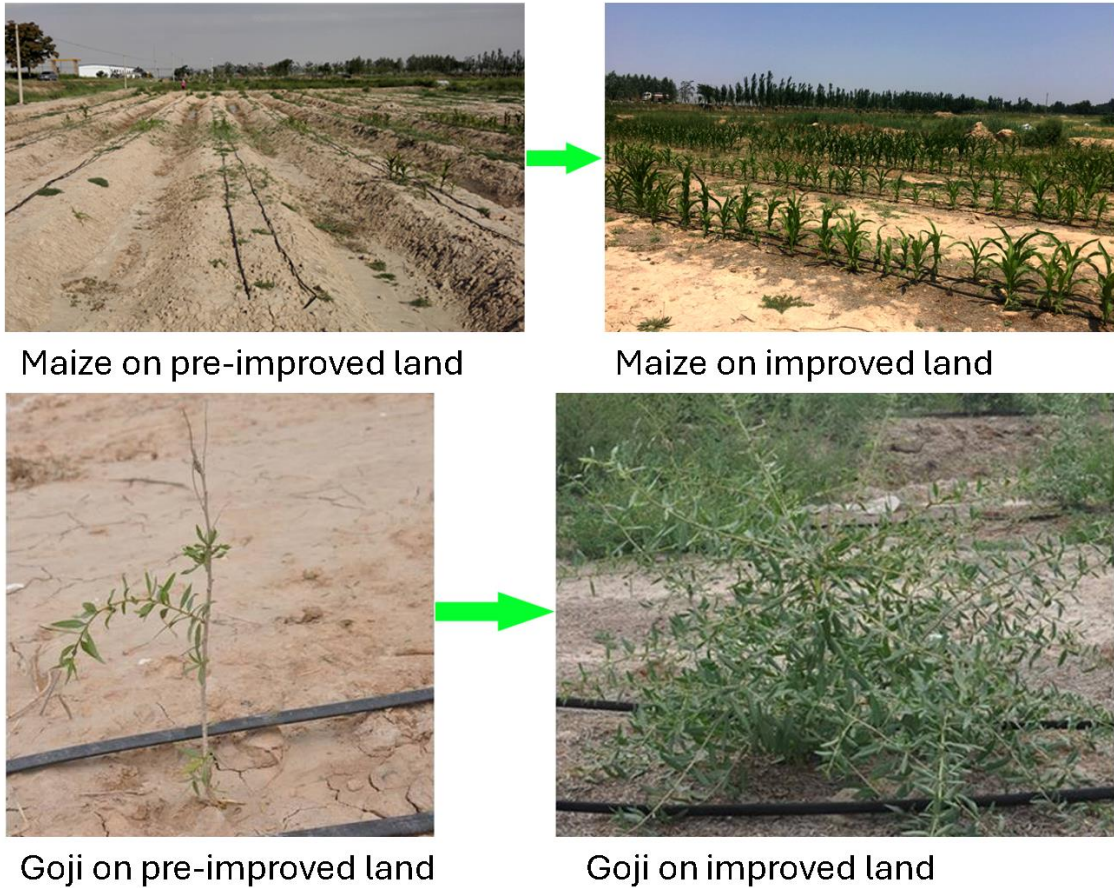


Fig. 4 Spatial-temporal changes of soil water and salt. I: Spatial-temporal changes of soil salt in 2017; II: temporal changes of soil salt in 2016; III: Spatial changes of soil salt in 2016.



**Fig.5 Growth comparisons of wolf berry and maize before and after amendment**

### 5. Stakeholder Insights:

Interviews with local experts and farmers revealed that past approaches to soil management often focused on single-species vegetation strategies for desertification control, which proved inadequate for long-term soil health. There is now a growing recognition of the need for integrated, ecosystem-based approaches to soil remediation.

### Discussion

The results of this study highlight the complex and multifaceted nature of soil salinization in Ningxia, emphasizing the need for integrated and sustainable remediation strategies. The high proportion of water

allocated to agriculture (90% compared to the national average of 65%) underscores the urgency of implementing water-efficient practices and technologies.

The effectiveness of biochar and organic amendments in improving soil properties aligns with findings from other arid and semi-arid regions (Saifullah et al., 2018). The positive impact of straw interlayers on root growth and microbial communities (Chen et al., 2024) suggests that locally available agricultural residues can play a crucial role in soil remediation strategies. This approach not only addresses soil health, but also provides a sustainable solution for agricultural waste management.

The success of controlled drip irrigation in rehabilitating saline soils (Sun et al., 2012) indicates that precision water management is critical for sustainable agriculture in water-scarce regions like Ningxia. Implementing such technologies could significantly reduce water usage while improving soil conditions. The insights gained from stakeholder interviews regarding past failures in soil management highlight the importance of adopting holistic, ecosystem-based approaches. Single-species strategies for desertification control have proven inadequate, suggesting that future remediation efforts should focus on promoting biodiversity and soil ecosystem multifunctionality.

Climate change projections indicating potential increases in soil salinization (Hassani et al., 2021) underscore the need for adaptive and resilient agricultural practices. Developing and implementing climate-smart agriculture techniques that consider both current and future environmental conditions will be crucial for long-term sustainability.

The economic implications of soil salinization, as highlighted by Qadir et al. (2014), emphasize the need for cost-effective remediation strategies. While biochar and advanced irrigation systems show promise, their widespread adoption may be limited by economic factors. Therefore, future research should focus on optimizing these technologies to improve their cost-effectiveness and accessibility to local farmers. In conclusion, addressing soil salinization in Ningxia requires a multi-pronged approach that integrates improved water management, soil amendments, and adaptive agricultural practices. Future policies and research should focus on promoting sustainable, ecosystem-based solutions that are tailored to local conditions and economically viable for farmers. This approach will not only help in reclaiming saline soils, but also will contribute to the overall sustainability and resilience of agriculture in the region.

## Conclusions

This comprehensive review of sustainable remediation strategies for saline soils in Ningxia, China, reveals the complex interplay between climate, agricultural practices, and soil health. The study underscores the critical nature of soil salinization in this region, where over 90% of water resources are allocated to agriculture, far exceeding the national average of 65%. This disproportionate water usage, coupled with Ningxia's arid to semi-arid climate, has exacerbated soil degradation and salinization, posing significant challenges to agricultural sustainability and food security.

The research highlights several promising approaches for sustainable soil remediation:

- 1) Wood chips incorporated into the soil are effective at reducing salinity, for improving soil structure, enhancing nutrient cycling, providing habitats for beneficial microorganisms, and for increased water capture and retention.
- 2) Biochar Application: The use of biochar, particularly derived from agricultural waste, has shown significant potential in improving soil structure, enhancing nutrient cycling, and providing habitats for beneficial microorganisms in saline soils (Yuan et al., 2023). This approach not only addresses soil health but also offers a sustainable solution for agricultural waste management.
- 3) Organic Amendments: The incorporation of organic materials, especially straw interlayers, has demonstrated remarkable improvements in soil organic carbon content, microbial activity, and root growth (Chen et al., 2024). A 5-cm thick straw interlayer was found to be particularly effective, suggesting that locally available agricultural residues can play a crucial role in soil remediation strategies.
- 4) Improved Irrigation Management: Controlled drip irrigation, maintaining specific soil matric potential levels, has proven effective in rehabilitating saline soils and promoting the growth of salt-tolerant plants (Sun et al., 2012). This precision water management approach is critical for sustainable agriculture in water-scarce regions like Ningxia.

- 5) **Integrated Ecosystem Approach:** The study reveals the limitations of past single-species strategies for desertification control. Future remediation efforts should focus on promoting biodiversity and soil ecosystem multifunctionality, adopting a more holistic, ecosystem-based approach to soil health.
- 6) **Climate-Adaptive Strategies:** Given the projections of increased soil salinization due to climate change (Hassani et al., 2021), developing and implementing climate-smart agricultural techniques is crucial for long-term sustainability and resilience.

However, the successful implementation of these strategies faces challenges, including the high costs associated with some technologies and the need for widespread adoption by local farmers. Future research and policy initiatives should focus on:

1. **Optimization and integration of remediation techniques:** Rational and comprehensive use of various technologies to leverage their strengths, enhance cost-effectiveness, and improve accessibility.
2. **Developing tailored solutions** that consider local ecological conditions and economic realities.
3. **Enhancing knowledge transfer and capacity building** among farmers and local agricultural stakeholders.
4. **Promoting integrated water and soil management practices** that address both immediate concerns and long-term sustainability goals.

In conclusion, addressing soil salinization in Ningxia requires a multi-faceted, sustainable approach that integrates improved water management, soil amendments, and adaptive agricultural practices. By adopting these strategies, it is possible to reclaim saline soils, enhance agricultural productivity, and contribute to the overall sustainability and resilience of agriculture in the region. This approach not only addresses the immediate challenges faced by Ningxia but also provides valuable insights for managing saline soils in other arid and semi-arid regions globally, contributing to broader efforts in sustainable land management and food security.

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