

Article

Practice of Improving Saline–Alkali Soil with Bio-Humic Acid

Chuyan Zhang ¹, Yingyun Qiao ^{2,*} and Qiang Song ¹

¹ College of Materials Science and Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China; zhappy03@126.com (C.Z.); sqxauat@126.com (Q.S.)

² State Key Laboratory of Heavy Oil Processing, China University of Petroleum (East China), Qingdao 266580, China

* Correspondence: qiao_yingyun@126.com

Abstract: The improvement and exploitation of saline–alkali soil is a hot topic worldwide. Analysis of soil aggregate structure and water and of the salt transport law, a new technology that uses humic acid as a saline–alkali soil amendment has been proposed. These advancements may effectively improve the soil aggregate structure of saline–alkali soil at the source. In this study, biological pyrolysis liquid was modified to produce soil modifier for saline–alkali land, and this soil modifier was used in a rice planting experiment. The results show that the application of a bio-humic acid soil amendment in the amount of 3000 kg/ha and its combination with humic acid fertilizer produced rice yields as high as 9750 kg/ha. At the same time, the pH of the soil was reduced from 10.81 to 8.95 (with bio-humic acid soil amendment content of 3000 kg/ha), and the soil organic matter demonstrated a trend of increasing with an increased amount of bio-humic acid soil amendment. The content of calcium, magnesium, and trace elements in the soil were clearly increased with the use of the amended soil in comparison with the normal group. With this amendment, saline–alkali land could be transformed and planted in the same year, increasing the potential yearly income for the land. This may be efficient and environmentally friendly, encouraging the agricultural circular economy.

Keywords: aggregate structure; improvement; saline–alkali formation; saline–alkali land; water and salt transport law



Citation: Zhang, C.; Qiao, Y.; Song, Q. Practice of Improving Saline–Alkali Soil with Bio-Humic Acid. *Processes* **2024**, *12*, 1250. <https://doi.org/10.3390/pr12061250>

Academic Editor: Guining Lu

Received: 11 May 2024

Revised: 11 June 2024

Accepted: 15 June 2024

Published: 18 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

At present, soil salinization is an urgent problem worldwide; therefore, it is important to find a solution. From a distribution perspective, there are about 9.55 million hectares of saline–alkali land worldwide [1,2]. The development of these saline lands has played a crucial role in the sustainable development of global agriculture and animal husbandry. Saline–alkali soil improvement and utilization have been hot topics internationally for some time. A series of saline–alkali land improvement technologies have been successfully developed (such as physical improvement [3], chemical improvement [4–6], hydraulic engineering improvement, biological improvement [7], etc.). However, the above technologies all have certain limitations which have become a bottleneck in the green sustainable improvement and development of saline–alkali land worldwide.

Typically, there is a dynamic equilibrium between groundwater and surface soil water in which the groundwater level remains constant while the salt ion content of the surface soil remains relatively stable. Research has shown that capillary water retention in soil was able to significantly enhance the number of gel-like particles with a particle size <0.25 mm. The porosity of the aggregate structure (>0.25 mm) used in this study was between 1.641 and 2.114 [8], which was able to block the phenomenon of capillary water in soil. Moreover, the formation of soil salinization was caused by the influence of natural factors or human factors, which led to a partial change in soil aggregate structure distribution. Following the addition of aggregates with a particle size >0.25 mm, an increase in gel-like particles with a particle size <0.25 mm was observed. Thus, the properties (such as bulk density,

water capacity, porosity, and permeability) of the soil were reduced, and its capillary water phenomenon was enhanced. When precipitation or irrigation cannot dilute the soil surface salt and drain away in time, the soluble salts are redistributed horizontally and vertically, resulting in the gradual accumulation of soil surface salts; the soil surface salt content can exceed 0.3%. This leads to “physiological drought” in the root cells of plants growing in arable land due to the large difference in salt concentration between inside and outside, inhibiting crop growth and even causing death. Thus, the integrated regulation of water–fertilizer–salt in the soil aggregate structure in order to improve saline–alkali soil is one of the most effective methods for the treatment of saline–alkali land.

Humic acid is the main component of humus and has a complex chemical structure. It contains active functional groups such as carboxyl, phenol, ketone, and phenol hydroxyl [8]. It is one of the most important components of soil organic matter. Many years of research and practice have proven that humic acid improves soil, enhances the efficiency of fertilizer, stimulates the growth of crops and microorganisms, improves crop resistance, and improves crop yield and quality. Humic acid originates from a wide range of sources, has a low cost, and demonstrates good compatibility in ecological environments. Thus, humic acid has been widely used in soil improvement and water conservation and has become a hot topic in the research on environmental remediation materials in recent years. Different humic acid components have differing soil remediation and treatment functions. For example, the low molecular weight of yellow algae can increase capacity and promote heavy metal activation, thereby improving the absorption of various heavy metal elements by enriched plants. The higher molecular weight brown and black humic acid can carry out ion exchange, complexation, and adsorption reactions, playing an active role in the adsorption, reduction, passivation, and fixation of heavy metal elements and reducing their mobility [2]. At present, the main source of humic acid products is mineral humic acid. However, mineral humic acid has certain limitations (such as low active components, high heavy metals content, high-concentration organic wastewater, etc. [9]). Therefore, it is urgent to solve the problem of how to carry out low-cost clean production of humic acid with high activity and content.

The common negative factors of saline–alkali land (such as “salt”, “alkali”, “thin”, “flat”, “cool”, etc.) present obstacles to its improvement, and it is difficult to find solutions that can be repeated. Based on the cause of saline–alkali soil, the advantages and disadvantages of various saline–alkali land improvement technologies were analyzed from the perspective of soil structure–water–salt integration [10]. In this study, a diagram of green and sustainable improvement for saline–alkali land is proposed in Figure 1. The practice of planting rice in the saline–alkali land that was improved by bio-humic acid was performed. We studied an analysis of the aggregate structure, pH, organic matter, and trace elements’ transformation law after soil improvement took place. The aim of this method is to eliminate the factors that affect the growth of crops in saline–alkali land, solve the phenomenon of salt return, and achieve a green, low-cost, in situ, and sustainable improvement of saline–alkali soil.

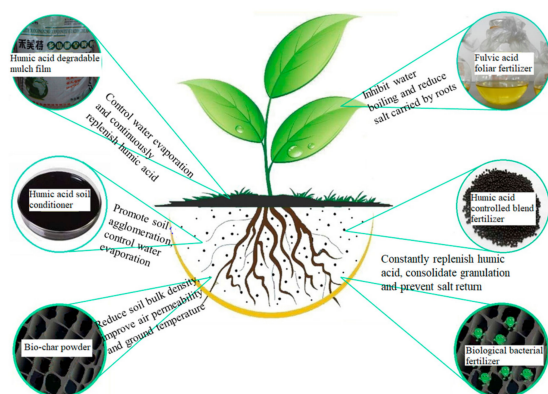


Figure 1. Diagram of green and sustainable improvement in saline–alkali land.

2. Material and Methods

The western region of Jilin Province is a concentrated area of saline–alkali land in China. The development of bio-humic acid using forestry and agricultural residues for saline–alkali land improvement exhibited good economic and ecological benefits. The test aimed to preliminarily verify the effect of applying bio-humic acid for saline–alkali land improvement and to provide a preliminary trial for the next testing and industrialization of the project.

2.1. Test Materials

(1) Soil amendment. A soil amendment for saline–alkali land was prepared by crop straw rapid pyrolysis (reaction conditions: reaction temperature of 520 °C, residence time of 400 ms, carrier regeneration temperature of 850 °C), which has the functions of “salt control, alkaline improvement, carbon enrichment and capacity reduction”. The viscosity and density of soil amendment were 100 mPa·s and 1.15 g/cm^{−3}, respectively.

(2) Previous studies found that the yield of rice could increase by 52.65 kg/ha using only humic acid chelate compared to its yield with other fertilizers. Thus, in this study, humic acid chelate fertilizer package was applied. The package was provided by Jilin Aojia Agricultural Science and Technology Co., Ltd., Songyuan, China. Rice package fertilizer includes: base fertilizer, humic acid chelate (18:15:12, HA ≥ 3%) at 600 kg/ha, humic acid silicon calcium fertilizer (SiO₂ ≥ 15%, CaO ≥ 8%, HA ≥ 14%) at 375 kg/ha. The topdressing at tillering stage was humic acid chelate (30:0:5, HA ≥ 4%) at 150 kg/ha. Humic acid foliar fertilizer at 375 kg/ha (15:5:20, HA ≥ 3%) was sprayed at heading and wax ripening stage. The saline soil was extracted from the test field through the ploughing and raking process.

2.2. Test Treatment Number

No. 1: 2250 kg/ha of humic acid soil amendment was applied, and the fertilization (rice fertilizer package) management was the same.

No. 2: 3000 kg/ha of humic acid soil amendment was applied, and the fertilization (rice fertilizer package) management was the same.

No. 3: 3750 kg/ha of humic acid soil amendment was applied, and the fertilization (rice fertilizer package) management was the same.

No. 4 (blank sample): no improvement, and the fertilization (rice fertilizer package) management was the same.

2.3. Field Management

(1) On 2 November 2022, soil amendment was applied and plowed.

(2) On 30 April 2023, the rice fields were ploughed and raked before the rice was transplanted.

(3) Field management was the same as the local rice planting management.

- ① Shallow water irrigation in rice cultivation mainly refers to the method of watering rice with a small amount of water after transplanting, which can replenish water for rice seedlings. Shallow water irrigation depth should generally be controlled at about 50% of the height of rice seedlings, and the maximum irrigation amount should not exceed 70% of the height of rice seedlings.
- ② From tillering stage to early stage of panicle differentiation of rice, it is necessary to remove all the water in the paddy field and dry the field.
- ③ In order to ensure the stable yield and quality of rice, attention should be paid to the application of nitrogen, phosphorus, potassium, and other fertilizers, as well as the appropriate application of trace elements.
- ④ All of the types of weeds and injurious insects in the field will compete for nutrients with rice and destroy photosynthesis, which is not conducive to a stable yield of rice nor to quality growth of rice. In this section, mechanical weeding and pesticides were used.

(4) Production measurement on 19 September 2023.

2.4. Crop Yield

The yield of crop was estimated using the panicle measurement method. In this method, the exact number of grain per panicle was calculated, and then, according to the number of grain per panicle in this field, the number of grain per panicle in other fields was calculated, and the total harvest was obtained.

3. Results and Discussion*3.1. Rice Yield before and after Improvement*

The number of plants per ha was measured, and the rice yield was measured according to the operation specification of agricultural crop yield measurement. The experimental data are shown in Table 1.

Table 1. Rice yield before and after soil improvement by biological humic acid and humic fertilizer.

Test No.	Effective Panicles/Hole	KNE ^a	TGW ^b	Output kg	20 Hole Fresh Grain Weight, kg	20 Hole Dry Grain Weight, kg	Equivalent Yield kg/ha
No. 1	22	97.5	22	0.602	0.928	0.795	8947.5
No. 2	23	115.6	22	0.746	1.129	0.879	9885.0
No. 3	22.3	98.4	22	0.616	0.878	0.760	8551.5
No. 4	4	25.0	22	0.028	0.041	0.035	393.0

^a KNE: kernels per spike. ^b TGW: thousand kernel weight.

As can be seen from Table 1, comparative tests were conducted on applying biological humic acid soil amendments of 2250 kg/ha, 3000 kg/ha, and 3750 kg/ha under the same management of fertilization (rice package fertilizer). Among these amounts, a soil amendment dosage of 3000 kg/ha produced the best yield (a total hole of 1000/ha). It was found that 20 holes were harvested continuously, the actual measured weight was 1.129 g, and the net weight after drying at 80 °C and 2.0 h was 0.878 Kg grams, which was equivalent to 9885.0 kg/ha. The yield of No. 4 was only 393.0 kg/ha, which shows that the bio-humic acid soil amendment clearly improved the performance of the saline–alkali soil, and this change could improve the planting benefits for the year.

*3.2. Physical and Chemical Properties of Soil before and after Improvement**3.2.1. Changes in Soil Aggregate Structure before and after Soil Improvement*

Before the improvement, saline soil was extracted from the test field according to the standard practice [11]. The saline soil treated with different amounts of bio-humic acid alkaline soil amendment was observed and measured using a capillary water elevation meter. The test instrument and results are shown in Figures 2 and 3, and the analysis of the aggregate structure treated with different amendments is exhibited in Figure 4. The soil's apparent morphology when treated with different amendments is shown in Figures 5 and 6.

Figures 2 and 3 show the capillary water rise height was about 74 cm without the soil amendment. The capillary water rise height was evidently decreased with an increase in the dosage of soil amendment. In particular, the amount of amendments increased to 1%, and the capillary water rise height reached to below 15 cm. This is likely due to the soil amendments' clear promotion of the formation of a soil aggregate structure and their ability to destroy the capillary phenomenon of soil [12]. The soil amendments also changed the law of water and salt transport and fundamentally blocked both the saline water from rising to the ground surface through the capillary phenomenon and the formation of salt and alkali by transpiration [6,9]. This was also confirmed by the structural differences of saline–alkali soils before and after improvement, as shown in Figures 4–6.



Figure 2. Experimental instrument for the height meter for capillary water rise.

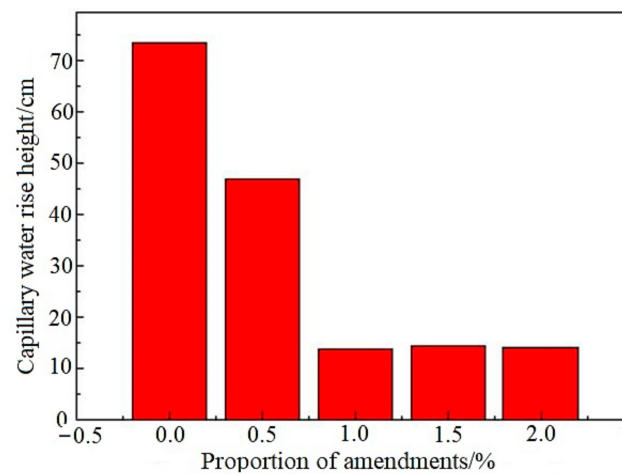


Figure 3. Capillary water rise height of soil improved by different proportions of amendments.

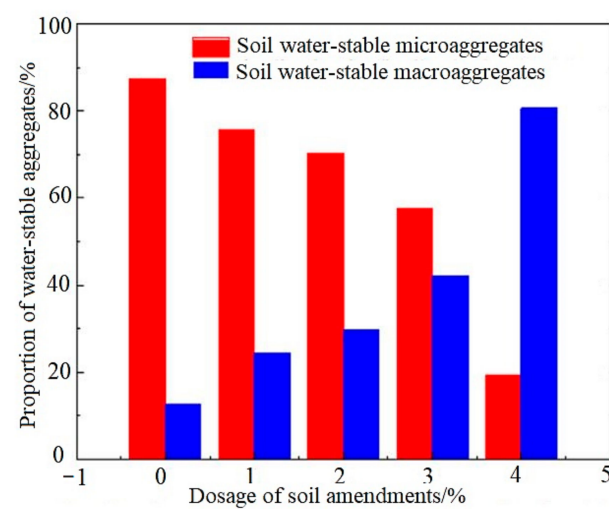


Figure 4. Distribution of large aggregates (≥ 0.25 mm) and micro-aggregates (< 0.25 mm) in soil before and after improvement.



Figure 5. Soil appearance after treatment with different bio-humate acid amendments (10%, 2%, 0%).



Figure 6. Cross-section of the morphology of soil with different bio-humate acid amendments (10%, 2%, 0%).

The analysis of the aggregate structure treated with different amendments is shown in Figure 4. Figure 4 shows the number of water-stable macroaggregates gradually increased, while that of water-stable microaggregates decreased, with an increased dosage of bio-humic acid amendment. Notably, the water stability of the soil reached 80% with the addition of 4% amendment. This exceeded the standard for garden nursery nutritive soil.

The soil apparent morphology under treatment with different amendments is shown in Figures 5 and 6. The soil surface morphology of saline–alkali soil improved with different bio-humic acid amendments when placed in a pot for 5 months. We observed that the soil mass structure was significantly increased, and the soil became loose and porous. Thus, the soil capillary damage was beneficial for the prevention of surface water evaporation and increased the soil’s bulk density and its water and fertilizer retention cap.

3.2.2. Changes in pH and Organic Matter after Soil Improvement

At the same time that rice yield measurement was carried out, soil samples were extracted from four kinds of comparative test fields, according to the standard practice [11], and sent to China Agricultural University for analysis and testing of the soil pH and organic matter content, as well as calcium, magnesium, and trace elements in order to further verify the feasibility of bio-humic acid improving the saline–alkali soil aggregate structure. The changes in soil pH and organic matter content after treatment with bio-humic acid soil amendment are shown in Figures 7 and 8 (of which No. 1, No. 2, No. 3, and No. 4 are shown in Section 2.2. Test Treatment Number).

Figure 7 shows the pH of the soil after the improvement was reduced. The pH of the soil after No. 3 was applied was reduced from 10.81 to 8.95 with the largest dosage of bio-humic acid soil amendment (3000 kg/ha). This likely occurred because the bio-humic acid used in this test has weak acidic active functional groups, such as hydroxyl, phenolic hydroxyl, and carboxyl, which are able to neutralize the alkalinity of saline–alkali soil. In addition, these active functional groups have strong ion exchange abilities, so that the bio-humic acid demonstrates good buffer performance. This was embodied in the fact that the pH value of the soil solution changed little. Then, we eliminated the impact of the saline–alkali soil acidity on crop growth and development.

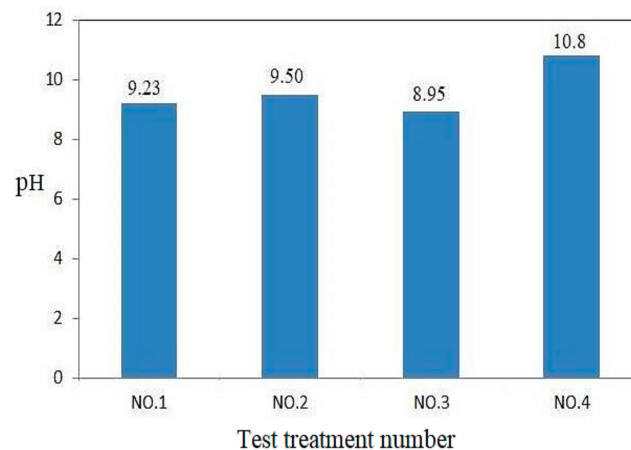


Figure 7. PH of different treatments of soil.

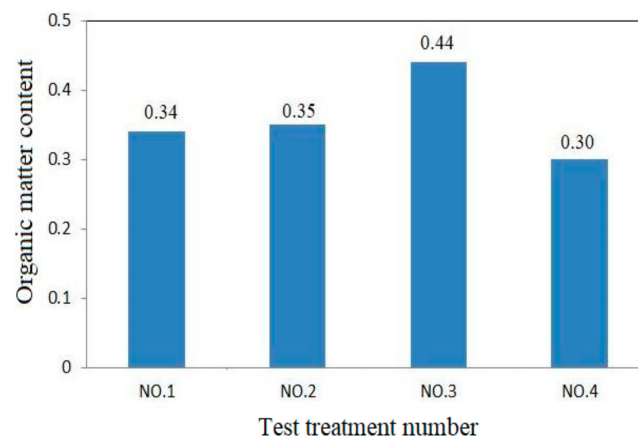


Figure 8. Organic matter of different treatments of soil.

The organic matter content after treatment with bio-humic acid amendment is shown in Figure 8. The soil organic matter presented an increasing with the application of an increasing amount of bio-humic acid soil amendment. Notably, the organic matter was higher than the amount of bio-humic acid soil amendment added to the surface soil. There are two possible reasons for these results [13,14]. On the one hand, this may have occurred because the bio-humic acid soil amendment itself was organic matter, which would increase the content of soil organic matter. On the other hand, the physical and chemical properties and biological activity of the saline–alkali soil were greatly improved after the application of the amendment, and the activity of microorganisms in the soil was greatly improved. The secretion and residue of bio-humic acid formed by microorganisms were greatly increased, which could also increase the content of organic matter in the soil.

3.2.3. Changes in Calcium, Magnesium, and Trace Elements after soil Remediation

The changes in calcium, magnesium, and trace elements in the soil after treatment with bio-humic acid saline–alkali soil amendment is shown in Figure 9 (of these, No. 1, No. 2, No. 3, and No. 4 are shown in Section 2.2. Test Treatment Number).

Figure 9a shows that the content of calcium and magnesium in the soil was significantly increased compared to the blank sample (No. 4). This indicates that the bio-humic acid was able to effectively dissociate and activate a large number of elements in the soil [15]. As can be seen from Figure 9b, in comparison with No. 4, the contents of Fe, Cu, and Zn in the soil of No. 1, 2, and 3 were all decreased, indicating that bio-humic acid was able to promote the activation and absorption of trace elements by crops and, as a result, improve crop quality. Therefore, bio-humic acid soil amendment can promote the effectiveness of calcium, magnesium, and trace elements in soil.

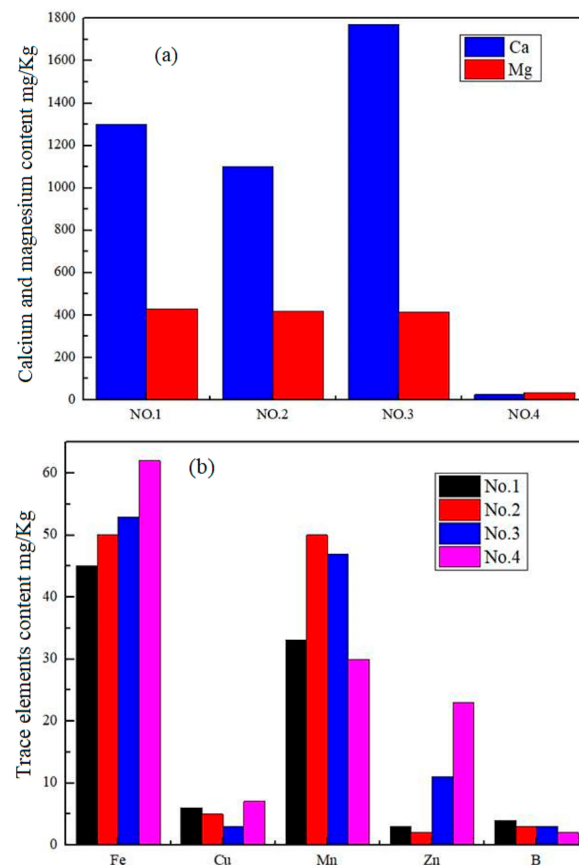


Figure 9. Transformation law of calcium, magnesium, and trace elements after soil remediation. (a) Content of calcium and magnesium after soil remediation, (b) Content of trace elements after soil remediation.

4. Conclusions

In this study, a new technology (integrated water–fertilizer–salt integrated) using humic acid as a saline–alkali soil amendment was put forward. This technology was able to effectively change the law of water and salt transport and fundamentally block the saline water from rising to the ground surface through the capillary phenomenon and forming salt and alkali by transpiration. This could solve the performance problems produced by the soil aggregate structure in saline–alkali soil at the source. The study shows results from the application of bio-humic acid soil amendment in the amount of 2250–3750 kg/ha. Meanwhile, the capillary water rise height clearly decreased with increasing dosages of soil amendment. Notably, the water stability of the soil reached 80% with the addition of 4% amendment. This exceeded the standard for garden nursery nutritive soil. In addition, the application of a series of bio-humic acid products clearly reduced the pH of soil. The pH of soil was reduced from 10.81 to 8.95 (with bio-humic acid soil amendment content of 3000 kg/ha), while the soil organic matter presented an increasing trend with the application of increasing amounts of bio-humic acid soil amendment. The content of calcium, magnesium, and trace elements in the soil was clearly increased through use of the soil amendment compared with the content in the normal group. Thus, changing to humic acid fertilizer may make it possible to plant more crops in saline–alkali land and increase yearly earnings.

Author Contributions: Conceptualization, C.Z. and Y.Q.; methodology, Y.Q. and Q.S.; validation, Y.Q. and Q.S.; formal analysis, Q.S.; investigation, C.Z. and Y.Q.; resources, C.Z. and Y.Q.; data curation, C.Z.; writing—original draft preparation, C.Z.; writing—review and editing, Y.Q. and Q.S.; visualization, C.Z., Y.Q. and Q.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Zhang, J.F.; Zhang, X.D.; Zhou, J.X.; Liu, G.H.; Li, D.X. World resources of saline soil and main amelioration measures. *Res. Soil Water Conserv.* **2005**, *12*, 28–30.
2. Tian, Y.L.; Liu, Y.S.; Zhang, H.B. Discussion of saline-alkali soil improvement technology and humic acid applied technology. *Humic. Acid.* **2018**, *3*, 42–46.
3. Zhang, L.; Zhai, Y.B.; Wu, C.Y.; Huang, S.; Zhang, Z. Modeling the interaction between a new four-bar subsoiling mechanism and red soil using the improved differential evolution algorithm and DEM. *Comput. Electron. Agric.* **2023**, *208*, 107783. [\[CrossRef\]](#)
4. He, H.S.; Wang, W.J.; Zhu, H.; Yuangang, Z.; Zhonghua, Z.; Yu, G.; Huinan, X.; Xingyang, Y. Influences on the seed germination and growth with addition of kriliams in saline-alkali soil. *Acta Ecol. Sin.* **2008**, *11*, 5338–5346.
5. Hao, Y.G.; Wang, S.J.; Li, Y.; Zhuo, Y.; Liu, J. Effects of straw layer and flue gas desulfurization gypsum treatments on soil salinity and sodicity in relation to sunflower yield. *Geoderma* **2019**, *352*, 13–21.
6. Fei, C.; Zhang, S.R.; Zhang, L.; Ding, X. Straw is more effective than biochar in mobilizing soil organic phosphorus mineralization in saline-alkali paddy soil. *Appl. Soil Ecol.* **2023**, *186*, 104848. [\[CrossRef\]](#)
7. Zhou, L.X.; Liu, W.; Duan, H.J.; Li, J.; Zhang, S.; Zhang, J.; Ding, S.; Xu, T.; Guo, B. Improved effects of combined application of nitrogen-fixing bacteria *Azotobacter beijerinckii* and microalgae *Chlorella pyrenoidosa* on wheat growth and saline-alkali soil quality. *Chemosphere* **2023**, *313*, 137409. [\[CrossRef\]](#)
8. Xia, G.H.; Guo, Q.X.; Lu, Q.M.; Du, Y.; Kang, Q. Soil nutrients and ecological stoichiometric characteristics under different land use patterns in loess hilly region. *Bull. Soil Water Conserv.* **2020**, *40*, 140–147+153.
9. Wu, Y.N.; Dong, H.R.; Tang, L.; Li, L.; Wang, Y.; Ning, Q.; Wang, B.; Zeng, G. Influence of humic acid and its different molecular weight fractions on sedimentation of nanoscale zero-valent iron. *Environ. Sci. Pollut. Res.* **2020**, *27*, 2786–2796. [\[CrossRef\]](#) [\[PubMed\]](#)
10. Sun, Z.J. *Research on Effects and the Mechanism of Desulfurization Gypsum and Humic Acid on Coastal Saline-Alkali Soil Improvement*; China University of Mining & Technology-Beijing: Beijing, China, 2013.
11. Wang, G.L.; Lu, W.J.; Zhou, W.S.; Song, C.Y.; Liu, N.S.; E, W.S. The Invention Relates to a Sampler for Soil Detection before Planting in Saline-Alkali Land and Sampling Method. Heilongjiang Province. Patent CN112504733A, 16 March 2021.
12. Wang, F.Y.; Wang, C.; Liu, Q.Q.; Jin, S.J.; Xie, Y.J. Improved effect of humic acid, earthworm protein fertilizer and vermicompost on coastal saline soils. *J. China Agric. Univ.* **2015**, *20*, 89–94. [\[CrossRef\]](#)
13. Chen, X.R.; Ma, M.L.; Zhou, S.M.; Hu, M.; Zhai, K.; Wei, S. Effect of initial conditions on the pore structure and bimodal soil–water characteristic curve of compacted granite residual soil. *Processes* **2024**, *12*, 409. [\[CrossRef\]](#)
14. Yang, X.Y.; Zhang, Y.M.; Chen, F.M.; Yang, Y. Interplay of natural organic matter with flow rate and particle size on colloid transport: Experimentation, visualization, and modeling. *Environ. Sci. Technol.* **2015**, *49*, 13385–13393. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Liang, B.; Xie, Y.Y.; Fang, Z.Q.; Tsang, E.P. Assessment of the transport of polyvinylpyrrolidone-stabilised zero-valent iron nanoparticles in a silica sand medium. *J. Nanoparticle Res.* **2014**, *16*, 2485. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.