Effects of Different Treatment Methods on Soil Nutrients of Saline–Alkaline Soil and Dandelion Growth

Ruiyuan Jin, Xunuo Zhao, Yibo Wang, Weijia Meng, Yanjun Ai*
College of Mining Engineering, North China University of Science and Technology, Tangshan, Hebei, China
**Corresponding Author*

Abstract: Soil salinization and alkalization seriously restrict agricultural sustainability and food security. To improve the low fertility and poor structure of saline–alkaline soil, a pot experiment was conducted using iron tailings, biochar, and microbial inoculants (Bacillus megaterium and Trichoderma harzianum). Their effects on soil pH and nutrient contents were evaluated.
The results showed that all treatments improved saline–alkaline soil properties. W30 (30% iron tailings) exhibited the strongest alkalinity-reduction effect, reducing soil pH to 8.17. W20s (20% iron tailings + biochar) showed the greatest nutrient enhancement, increasing soil organic carbon by 9.84% and available nitrogen by 72.42% compared with CK. W20 (20% iron tailings) produced the highest available phosphorus content.
These findings indicate that the combined application of iron tailings, biochar, and microbial inoculants exerted microbial specificity and dosage-threshold effects on saline–alkaline soil properties. Appropriate amendment rates can effectively reduce soil alkalinity and improve nutrient availability.

Keywords: Saline–Alkaline Soil; Iron Tailings; Biochar; Microbial Inoculants; Nutrient Availability; Ecological Restoration

1. Introduction

Soil salinization and alkalization threaten sustainable agriculture and food security, and physicochemical amendments have become an important strategy for saline–alkaline soil remediation [1]. Biochar can improve soil properties and microbial activity because of its porous structure and high adsorption capacity [2], whereas microbial inoculants promote nutrient cycling, plant salt tolerance, and rhizosphere improvement [3]. Iron tailings, a mineral-rich mining waste, can also enhance soil properties. However, studies on the combined application of these amendments remain limited. Therefore, pot experiments were conducted using different proportions of iron tailings and biochar combined with Bacillus megaterium or Trichoderma harzianum to evaluate their effects on soil pH and available nutrient contents.

2. Materials and Methods

2.1 Soil Sampling

Saline–alkaline soil was collected from Caofeidian District, Tangshan, Hebei Province, China. The soil had a pH of 9.07, organic carbon of 7.18 g/kg, available nitrogen of 53.9 mg/kg, available phosphorus of 7.97 mg/kg, and available potassium of 209 mg/kg.

2.2 Experimental Design

Both saline–alkaline soil and iron tailings were passed through a 2-mm sieve before use. Thirteen treatments were established: CK; 20% iron tailings (W20); 30% iron tailings (W30); W20 + 1% biochar (W20s); W30 + 1% biochar (W30s); W20 + Bacillus megaterium (W20y); W30 + Bacillus megaterium (W30y); W20 + Trichoderma harzianum (W20h); W30 + Trichoderma harzianum (W30h); W20 + biochar + Bacillus megaterium (W20sy); W30 + biochar + Bacillus megaterium (W30sy); W20 + biochar + Trichoderma harzianum (W20sh); and W30 + biochar + Trichoderma harzianum (W30sh). Iron tailings were added at 20% or 30% (v/v), while biochar was applied at 1% (w/w). Each treatment included three replicates (39 pots in total).

Microbial inoculants were prepared by diluting 25 mL inoculum with 500 mL sterile water. Dandelion (Taraxacum officinale) was grown in each pot. At 12 and 18 weeks after sowing, 40 and 50 mL diluted inoculum, respectively, were applied to each pot, whereas the control received equal volumes of water. Pots were irrigated regularly and kept weed-free. Soil, shoots, and roots were collected 22 weeks after sowing for subsequent analyses.

2.3 Measurements and Statistical Analysis

Soil pH was measured at a soil-to-water ratio of 1:5. Available nitrogen, available phosphorus, available potassium, and organic carbon were determined using the alkaline hydrolysis diffusion method, sodium bicarbonate extraction–molybdenum antimony colorimetric method [4], flame photometry [5], and potassium dichromate oxidation method [6], respectively.

Plant samples were heated at 105°C for 30 min and dried at 70°C for 24 h before dry weight determination. Data were processed using Excel and SPSS, with Duncan's multiple range test used for significance analysis. Figures were prepared using Origin.

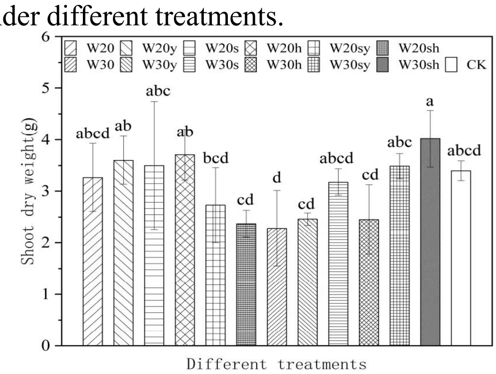
2.4 Statistical Analysis

Data were compiled and summarized using Microsoft Excel. Statistical analyses and Duncan's multiple range tests were performed using SPSS, and figures were generated using Origin.

3. Results and Analysis

3.1 Analysis of Dandelion Biomass

Figure 1 and Figure 2 show dandelion biomass under different treatments.



Note: Different letters indicate significant differences among treatments (P < 0.05). The same notation

Figure 1. Dandelion Aboveground Biomass

The shoot and root dry weights in CK were 3.40 g and 17.27 g, respectively. The addition of 20% iron tailings had little effect on dandelion growth, whereas 30% iron tailings significantly inhibited growth, reducing shoot and root biomass by 1.12 g and 3.57 g, respectively, compared with CK. Biochar alleviated this inhibitory effect, as dandelion biomass under W30s was significantly higher than that under W30 ($P < 0.05$) and did not differ significantly from CK. Within the W30 treatments, combining biochar with either Bacillus megaterium or Trichoderma harzianum further mitigated the inhibitory effect of iron tailings on shoot growth.

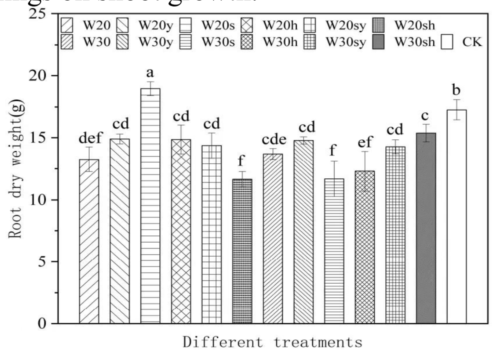


Figure 2. Dandelion Belowground Biomass

3.2 Effects of Different Treatments on Soil pH

The soil pH value of CK was 8.43.All treatments significantly reduced soil pH ($p < 0.05$).Among the W20 treatments, W20 and W20sy exhibited significantly lower pH values than the other treatments, reaching 8.20 and 8.19, respectively.Among the W30 treatments, no significant differences were observed among treatments, and W30 showed the lowest pH value of 8.17.

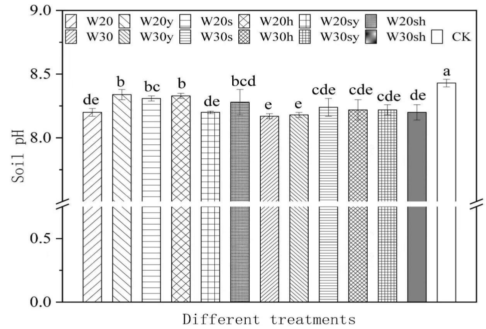


Figure 3. Soil pH

3.3 Effects of Different Treatments on Soil Organic Carbon

The addition of iron tailings generally reduced soil organic carbon content.The organic carbon contents of W20 and W30 were 76.84% and 67.63% of CK, respectively.The addition of biochar and inoculation with Bacillus megaterium or Trichoderma harzianum promoted the accumulation of soil organic carbon.Biochar showed the most pronounced effect.The organic carbon contents of W20s and W30s increased by 42.95% and 17.29%, respectively, compared with the corresponding iron-tailings-only treatments.The organic carbon content of W20s was significantly higher than that of CK.However, the organic carbon content of W30s remained significantly lower than that of CK.

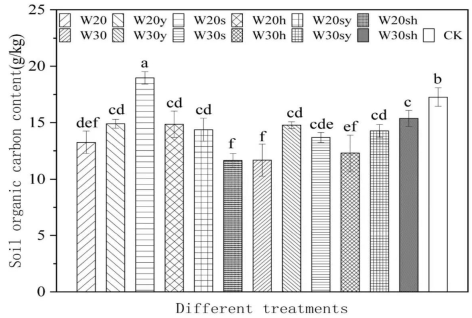


Figure 4. Soil Organic Carbon Content

3.4 Effects of Different Treatments on Available Nitrogen

The addition of 20% iron tailings activated soil nitrogen.Further addition of biochar or inoculation with Bacillus megaterium produced more pronounced increases in available nitrogen.The available nitrogen contents of W20, W20y, and W20s reached 1.21, 1.29, and 1.67 times that of CK, respectively.After the addition of 30% iron tailings, available nitrogen slightly decreased.However, the addition of biochar significantly increased available nitrogen.The available nitrogen content of W30s reached 1.49 times that of CK.

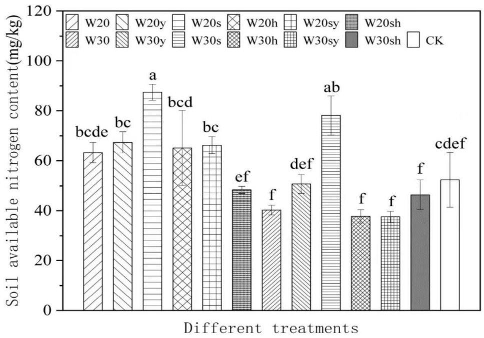


Figure 5. Soil Available Nitrogen Content

3.5 Effects of Different Treatments on Available Phosphorus

In the 20% iron-tailings treatments, available phosphorus contents were higher than those of CK, with W20 showing the highest value, 12.93% above CK and significantly higher than all other treatments. Microbial inoculants in the W20 series also increased available phosphorus, although less effectively than W20 alone. In contrast, no significant differences were observed between the 30% iron-tailings treatments and CK, suggesting a threshold effect of iron tailings on phosphorus activation, with excessive application suppressing phosphorus release. Moreover, microbial inoculants showed no significant synergistic effect on phosphorus activation.

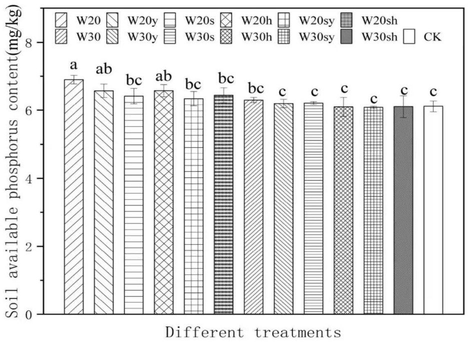


Figure 6.Soil Available Phosphorus Content

3.6 Effects of Different Treatments on Available Potassium

W20y showed the highest available potassium content, 7.36% higher than CK and significantly higher than all other treatments ($P < 0.05$), whereas the remaining W20 treatments and all W30 treatments were lower than CK. The lowest value was observed in W30sy, which was 19.3% lower than CK. In both the W20 and W30 series, combined biochar–microbial treatments had lower available potassium contents than the corresponding single-amendment treatments, suggesting that Bacillus megaterium specifically promoted potassium activation under the 20% iron-tailings system, whereas higher iron-tailings dosage and combined microbial treatments may reduce potassium availability through competitive adsorption or metabolic inhibition.

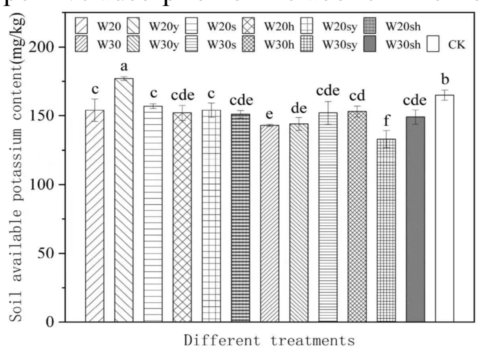


Figure 7. Soil Available Potassium Content

4. Conclusions

The combined application of iron tailings, biochar, and microbial inoculants effectively improved saline–alkaline soil properties, although the effects differed among treatments. W30 showed the greatest pH reduction (8.17), whereas W20sy achieved a comparable effect at a lower iron-tailings dosage, consistent with Xia et al. [7]. W20s most effectively increased soil organic carbon and available nitrogen by 9.84% and 72.42%, respectively, supporting previous findings on the role of biochar in nutrient transformation [8]. However, soil organic carbon was lower than CK in most treatments, possibly because of the low organic carbon content of iron tailings [9]. W20 resulted in the highest available phosphorus, consistent with Chen et al. [10], whereas microbial inoculants did not further enhance phosphorus availability, unlike the findings of Qin et al. [11]. W20y most effectively increased available potassium, likely through potassium activation by Bacillus megaterium [8]. Several nutrient indicators were lower in W30 than in W20, suggesting a threshold effect of iron-tailings dosage consistent with previous reports [12]. These findings highlight the importance of selecting amendment combinations according to specific saline–alkaline soil remediation objectives.

Acknowledgements

This work was supported by he Project supported by the Central Guiding Local Technology Development Funds Project of Hebei Province, China (No. 246Z7610G) and the Undergraduate Innovation and Entrepreneurship Training Program of North China University of Science and Technology (Project No. X2025096).

References

[1] Liu, J.J. Application of ecological restoration technologies in mining soils. Energy and Environment, 2023(2): 115–117.

[2] Wei, Y., Gao, H.J., Yuan, R., et al. Application of modified biochar in saline–alkaline land restoration. Soil Science, 2023, 11(2): 73–78.

[3] Dilfuza, E., Stephan, W., Dorothea, S.B., et al. Salt-tolerant plant growth-promoting rhizobacteria for enhancing crop productivity of saline soils. Frontiers in Microbiology, 2019, 10:2791.

[4] Sun, P., Zhang, T., Zhang, H.L., et al. Research on salt-isolation and desalination materials and technologies for saline soils. Salt Science and Chemical Industry, 2023, 52(10): 6–9.

[5] Li, X.X. Determination of seven metallic elements in soil by inductively coupled plasma emission spectrometry. Chemical Engineer, 2024, 38(6): 32–34.

[6] Jia, L., Liu, L.Y., Zhang, T., et al. Application of soil amendments in ecological restoration of saline soils. Journal of Hunan Ecological Science, 2023, 10(3): 92–99.

[7] Xia, X.Y., Wang, C.W., Yu, P.J., et al. Improvement effects of novel iron-tailings-based composite amendments on saline–alkaline soils in the Songnen Plain. Soil and Crop, 2025, 14(3): 360–371.

[8] Lin, C., Chen, X.L., Zhan, J., et al. Advances in the application of microbial inoculants in saline–alkaline soil remediation. Marine Sciences, 2025, 49(4): 95–105.

[9] Cui, X.W., Geng, Y., Li, T., et al. Field application and effect evaluation of different iron-tailings soil utilization technologies. Resources, Conservation and Recycling, 2021, 173:105746.

[10] Chen, Y.X., Liu, Z.K., Huang, Y.X. Research progress on the application of iron tailings in saline–alkaline land remediation. Journal of Inner Mongolia Agricultural University (Natural Science Edition), 2025, 46(5): 93–100

[11] Qin, J.J., Yang, W., Zhang, R.X., et al. Emission reduction and yield enhancement effects of combined biochar and microbial fertilizer application in saline–alkaline land improvement. Journal of Soil and Water Conservation, 2025, 39(1): 274–283.

[12] Wang, X.D., Li, M., Zhang, H.N., et al. Effects of different saline–alkaline stresses on pepper growth and yield. Agriculture and Technology, 2025, 45(9): 12–15.

