

Research Article

Effect of Biomass Improvement Method on Reclaimed Soil of Mining Wasteland

Yanfei Xu,^{1,2} Shikai An,^{1,2} Yongchun Chen,^{1,2} Chao Yuan ,³ and Pengfei Tao^{1,2}

¹National Engineering Laboratory for Protection of Coal Mine Eco-Environment, Ping an Mining Engineering Technology Research Institute Co., Ltd., Huainan 232001, China

²Coal Mining National Engineering Technology Research Institute, Huainan, Anhui 232001, China

³School of Resource & Environment and Safety Engineering, Hunan University of Science and Technology, Xiangtan, Hunan 411201, China

Correspondence should be addressed to Chao Yuan; yuanchaozh1@126.com

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Aiming at the problem of soil improvement for mining wasteland reclamation, this article takes the coal mining subsidence reclamation area of a coal mine in the east of China as the research object. Compost improvement and green manure improvement experiments were carried out to study the impact of different biomass improvement methods on the quality of reclaimed soil. 10 soil physical and chemical indicators including water content, total nitrogen, ammonia nitrogen, nitrate nitrogen, available phosphorus, available potassium, total phosphorus, organic matter, pH, and conductivity were selected to evaluate the effect of soil improvement. After 5 months of soil improvement, the results showed that planting alfalfa and Mexican corn in the reclaimed area can increase soil available phosphorus, available potassium, total phosphorus, and organic matter content. Cattail, a common aquatic plant in the coal mining subsidence area in the east, is used to make organic compost. When the compost is applied to reclaimed soil, the content of available phosphorus, available potassium, and total phosphorus in the soil can be significantly increased. Using white vanilla clover as green manure for reclaiming soil can significantly increase the content of nitrate nitrogen, available phosphorus, available potassium, and total phosphorus in the soil. Biomass improvement technology can improve the fertility level of coal mine reclamation soil in a short time. It is conducive to promoting the restoration of soil fertility of mining wasteland and realizing the sustainable development and utilization of plant resources and land resources.

1. Introduction

With abundant coal resources, China is one of the major coal mining countries in the world. The continuous exploitation of coal resources contributes to the gradual closure of many coal mines [1]. According to “Strategic Studies of High-Efficient and Energy-Effective Coal Extractions in China,” a key consulting project of the Chinese Academy of Engineering, the number of abandoned coal mines in China can reach 15 000 by 2030. The increasing abandoned coal mines finally generate a lot of mining wasteland. Ecological restoration of mining wasteland is one of the important topics in the development and utilization of abandoned coal mines [2].

Soil serves as a material basis for human survival. It is basic for crop growth, food, and animal production, thus

being the material basis for human survival and development. In the study of remediation and utilization of abandoned coal mines, soil reconstruction and soil quality improvement and capacity increase have been the research hotspots [3, 4]. The existing research results show that the soil quality of mining wasteland deteriorates to varying degrees because of the exploitation of coal resources in the long time series, which leads to the changes in soil moisture, structure, fertility, and material composition in mining areas. For example, Wei et al. found that the soil water content in mining subsidence areas is generally smaller than that in nonsubsidence areas [5]. Huang and Luo found that the contents of organic matter, nitrogen, and phosphorus in the mining area soil were only 20%~30%, compared with those in the vegetation-covered soil [6]. A good many

research results show that the structure, fertility, pH value, and other aspects of the reconstructed soil in the mining area are greatly different from those in the ordinary farmland, and the soil productivity is difficult to reach the same level as the previous or cultivated soil [7–9]. The recovery of damaged land in mining areas is very slow, and in the process of land remediation and utilization of mining wasteland, how to improve the reclaimed soil, enhance the quality of mining soil, and restore land productivity is one of the key issues in land reclamation of mining wasteland [10–14].

Huainan Coalfield has a coal mining history of more than 100 years. It is one of 14 important large-scale coal bases and six coal-electricity bases in China. Located in the northern central part of Anhui Province, it is the coalfield with the best coal resources and the largest coal reserves in the eastern and southern regions of China at present. The coal resources provide a strong support for the rapid social and economic development of Huainan [15–17]. However, coal mining has led to the formation of large-scale subsidence areas. At present, the subsidence area of Huainan Coalfield is about 240 km² (calculated according to the subsidence line of 0.1 m). Huainan Coalfield is a Middle-Eastern plain area with coal, grain, and population highly concentrated. About 50% of the subsidence areas have become waterlogged areas and cannot be cultivated at all, while in the other 50%, affected by seasonal rain, some areas may not be cultivated [18, 19]. Coal mining has caused a series of problems concerning village relocation, compensation, resettlement, land-lost farmers' employment, social security, and so on. In order to restore cultivated land, integrate land resources, alleviate the contradiction between man and land, and restore the function of the regional ecosystem, many efforts in land reclamation have been made in the subsidence areas, which is of great significance to realize the sustainable development of Huainan Coalfield [20]. After land reclamation in the subsidence areas, the soil structure and properties have changed greatly compared with the original soil [21]. Land reclamation and reconstruction of soil in the subsidence areas often destroy the original structure and layer profile of soil due to mechanical crushing in the process. The physicochemical properties and fertility level of the reconstructed soil have changed greatly. The structure, fertility, and pH value of the reconstructed soil are still quite different from those of the ordinary farmland, so the productivity of the soil was difficult to reach the same level as the previous or cultivated soil [22]. And Huainan Coalfield is located in areas with high groundwater levels, and the depth of the subsidence area is generally more than 1.5 m, which forms the water area. Due to the function of soil capillaries and evaporation, salt accumulation in the surface soil leads to land salinization, and therefore, crops gain poor growth and low yields. Land productivity has been affected severely. It has brought a great harmful impact on the ecological environment of the region and threatened the regional ecological security [23].

Aiming at the problem of poor soil quality in the reclamation of mining wasteland, compost improvement and green manure improvement experiments were carried out to study the impact of different biomass improvement methods on the quality of reclaimed soil in this paper.

2. Materials and Methods

2.1. Methods of Land Reclamation. In order to study the effect of biomass improvement on the reclaimed soil quality of mining wastelands, the reclamation area of Xinzhuangzi coal mine in Huainan Coalfield is selected to study. The geographical location of the study area is shown in Figure 1. The control area of Xinzhuangzi Coal Mine Geological Environment Treatment Project is 22.87 hm². The method of reclamation of coal mining subsidence areas is to fill coal gangue. Firstly, coal gangue is filled in waterlogged subsidence areas, and then, loess is covered on the surface of coal gangue. The gangue is filled in layers, and 0.4 m is filled each time. The large particle size of gangue is backfilled to the bottom of the subsidence area, then the small particle size of gangue is backfilled, and next, a small amount of loess is added into the gangue to improve the water retention property. Each layer of the gangue filled in layers is rolled for more than 8 times. After the coal gangue filling, 1.0 m of thick loess covers the surface. The land structure of the gangue-filled reclamation area is shown in Figure 2. The land reclamation process is shown in Figure 3. After the topsoil layer is covered with soil, woody plants such as *Metasequoia*, *Ligustrum lucidum*, and peach trees are planted. After the planting for a period, soil hardening occurred, and the survival rate of *Metasequoia* was low. In study areas, field investigation, sampling and indoor analysis, and determination of samples were finished to clarify the types and spatial distribution of surface soil degradation and to figure out the main factors affecting the survival and development of plant communities in degraded soil [24]. The physical and chemical indicators of the reclaimed soil and the control farmland soil showed that the pH of the reclaimed soil was higher than that of the control farmland, being weak alkali. The four indicators, organic matter, available phosphorus, total potassium, and total phosphorus, were lower than the control farmland. The physical and chemical indicators of the reclaimed soil and the control farmland soil are shown in Table 1.

2.2. Soil Improvement Method. In order to improve the soil quality of the reclamation area, compost improvement and green manure improvement experiments were carried out in the study area, and then, the fertility index of the improved soil was measured and analyzed to study the impact of different biomass improvement methods on the quality of reclaimed soil.

2.2.1. Experimental Design of Compost Improvement

(1) Compost Preparation. The aquatic plant *Cattail* in the coal mining reclamation area is the main ingredient of organic compost. The compost can be divided into 4 types according to different auxiliary materials added in the composting process. Nutrient content in each type of compost is shown in Table 2.

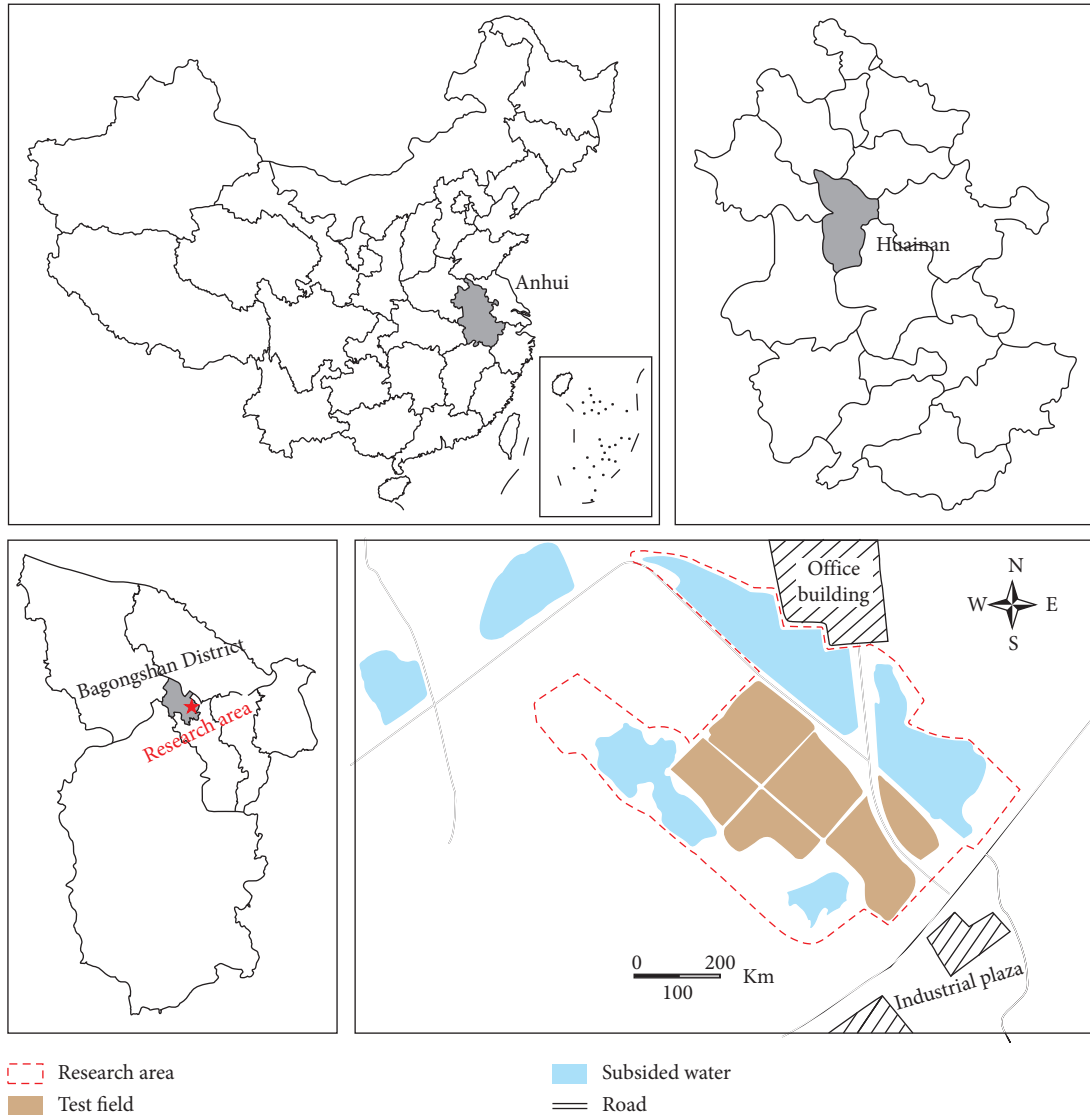


FIGURE 1: Geographical location of the study area.

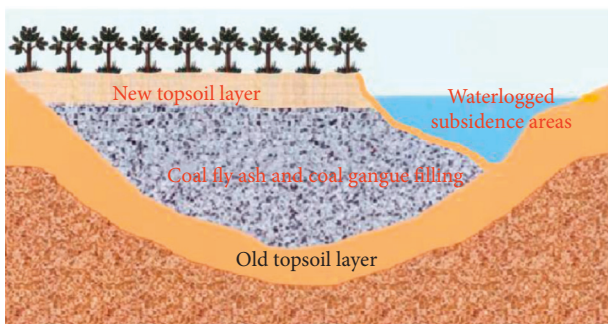


FIGURE 2: Diagram of filling the reclamation area of mining subsidence land.

(2) *Test Scheme of Compost Improvement.* Different types of compost are randomized into 11 groups for the compost improvement test, of which 8 treatment groups and 3 control groups are designed. The experimental design is shown in Table 3. Each treatment group covers an area of

200 m² and 0.9 kg/m² of organic compost being used in the experiment. The other three control groups are without fertilizer application. Alfalfa and Mexican corn are sown in each group after soil tillage. Alfalfa and Mexican corn are both salt-tolerant and barren tolerant and are suitable for growing on the reclaimed soil of mining wasteland. At the same time, they have the function of improving soil and are widely planted as forage grass in the local area. Therefore, we choose these two plants as experimental vegetation for soil improvement.

2.2.2. *Experimental Design of Green Manure Improvement.* White vanilla clover, a nitrogen-fixing leguminous plant growing in winter and early spring, is used as green manure. After soil tillage, white vanilla clover is planted in topsoil to increase the content of phosphorus and organic matter and improve the soil structure and boost fertility and water retention capacity. Different types of green manure are randomized into 3 groups for the green manure

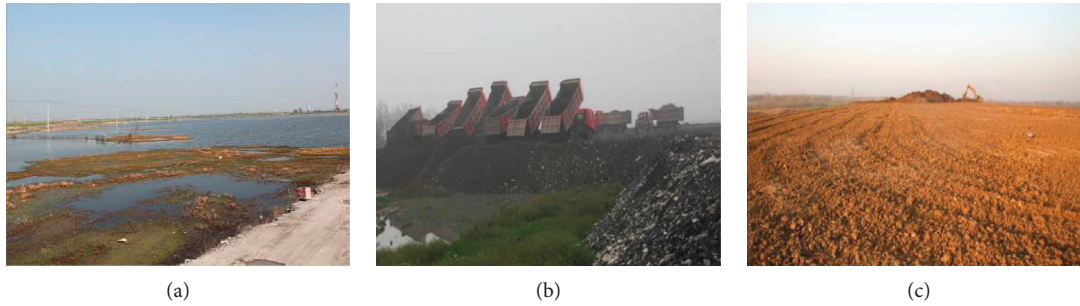


FIGURE 3: Land reclamation process of mining wasteland. (a) Original condition of mining subsidence area. (b) Filling coal fly ash and coal gangue. (c) Covering the surface soil.

TABLE 1: Physical and chemical indicators of the reclaimed soil and the control farmland soil.

Soil type	pH	Bulk density (g/cm ³)	Organic matter (g/kg)	Available phosphorus (mg/kg)	Total potassium (g/kg)	Total phosphorus (g/kg)
The reclaimed soil	8.06	1.35	12.80	11.84	21.21	0.22
The control farmland soil	7.58	1.28	13.51	13.92	22.67	0.31

TABLE 2: Contents of nitrogen and phosphorus in organic fertilizers.

Type of organic fertilizer	Total N (%)	Available N (%)	Total P (%)	Available P (%)
NO.1	2.04	0.252	0.787	0.046
NO.2	1.71	0.231	0.949	0.226
NO.3	1.43	0.078	0.377	0.176
NO.4	1.67	0.171	0.761	0.121

TABLE 3: Experimental design for compost improvement in the reclamation area.

Type	Grasses	Type of organic fertilizer	Group name	Experimental area (m ²)	Amount of compost (kg/m ²)	Depth of improvement (cm)
Ecological restoration experiment in covering soil layer with trees and leguminous grass planted, plus compost improvement	Alfalfa	NO.1	Z1	200	0.9	20
		NO.2	Z2	200		
		NO.3	Z3	200		
		NO.4	Z4	200		
Ecological restoration experiment in covering soil layer with trees and gramineous grass planted, plus compost improvement	Mexican corn	NO.1	M1	200	0.9	20
		NO.2	M2	200		
		NO.3	M3	200		
		NO.4	M4	200		
Control group 1	Alfalfa Mexican corn	Nontreated	DZ	70	0	20
		Nontreated	DM	70		
Control group 2	—	Nontreated	CK	800	0	0

improvement test, of which 2 treatment groups and 1 control group are designed. The experimental design is shown in Table 4.

2.3. Sample Collection and Processing. As for the collection of soil samples, stratified sampling shall be done according to soil profiles. During land reclamation, after filling gangue in a waterlogged area, 1.0 m of thick loess covers the surface. As the 1-meter-thick loess is homogeneous, samples should be collected in layers according to the technical specification for soil environmental monitoring

in the environmental protection industry standard of the People's Republic of China. A sampling layer is divided every 20 cm from the surface, and samples are taken in the middle of each sampling layer to study the vertical distribution characteristics of soil nutrients in the soil. Therefore, in this paper, samples were collected from three soil layers at depths of 0–20 cm, 20–40 cm, and 40–60 cm, respectively. The arrangement of sampling points is shown in Figure 4. When sampling, mark off the sampling section within the depth range of sampling and take out soil samples layer by layer from top to bottom. Put soil samples in a bag, stick a label prepared before, and then

TABLE 4: Experimental design for green manure improvement in the reclamation area.

Type	Name	Group name	Experimental area (m ²)	Green plants	Depth of improvement (cm)
Ecological restoration experiment in covering soil layer with trees and leguminous grass planted, plus green manure improvement	Alfalfa	LZ	5.300	White vanilla clover	20
Ecological restoration experiment in covering soil layer with trees and gramineous grass planted, plus green manure improvement	Mexican corn	LM	5.300	White vanilla clover	20
Control group	—	CK	2.000	Nontreated	20

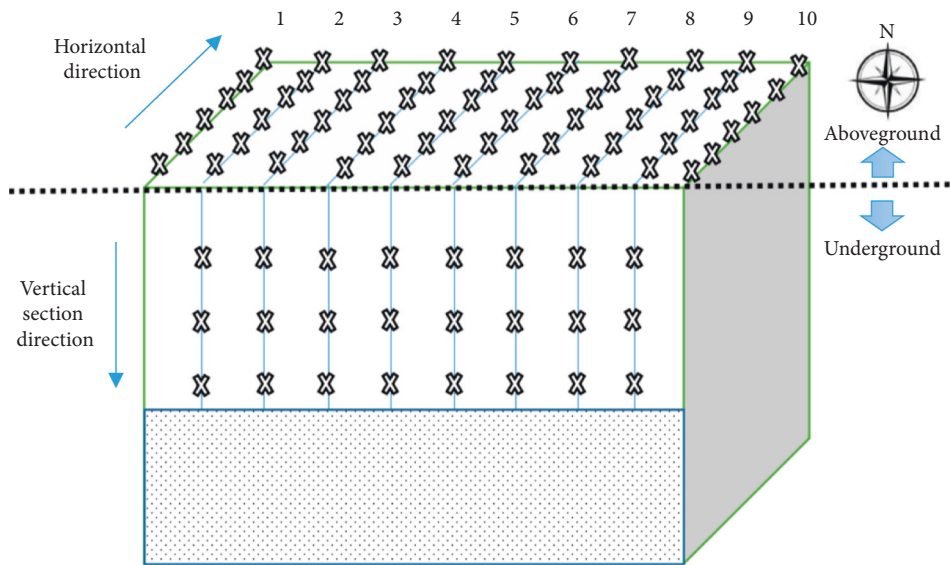


FIGURE 4: Distribution of sampling points.

bring them back to the laboratory. The samples were poured on a clean and dry plastic film or on a porcelain plate for natural air drying. The air-dried soil samples were ground, sieved (2 mm and 0.25 mm), placed in a dryer, and stored at room temperature, in a shade, cool, dry, and sealed environment [25]. The collection and processing process of soil samples is shown in Figure 5.

2.4. Soil Sample Testing. In order to ensure the accuracy of the test data, the unified test method of China is adopted for testing. The test standards and specifications used include soil technical analysis standard, soil environmental quality standard, and agricultural industry standard of the People's Republic of China. The measurement methods and standards of each index are shown in Table 5.

3. Results and Analysis

After 5 months of using compost and green manure to improve the reclaimed soil and planting grasses, the topsoil of the study area is sampled, and 10 soil physical and chemical indicators including water content, total nitrogen, ammonia nitrogen, nitrate nitrogen, available phosphorus, available potassium, total phosphorus,

organic matter, pH, and conductivity are selected to evaluate the effect of soil improvement and to analyze the soil improvement effect.

3.1. Analysis of the Soil Improvement Effect by Growing Grasses. The fertility test data of control group 1 and control group 2 are compared to analyze the improvement effect on soil with grasses planted. As shown in Figure 6, compared with the control group CK, the available phosphorus increased by 60% and 55% in the reclamation areas of DZ and DM, respectively, the available potassium increased by 19% and 10%, the total phosphorus increased by 33% and 70%, and the organic matter increased by 40% and 8%.

There are no significant increases in water content, total nitrogen, ammonia nitrogen, nitrate nitrogen, pH, and conductivity of the topsoil. The results show that planting alfalfa and Mexican corn in reclaimed soil has little effect on the six soil indexes, so the six soil indexes are not analyzed. The results show that planting alfalfa and Mexican corn in the reclamation area can increase the contents of available P, available K, total P, and organic matter. And the content of available P in the topsoil is significantly increased. For organic matter, available phosphorus, total potassium, and total phosphorus contents are lower than the control group,

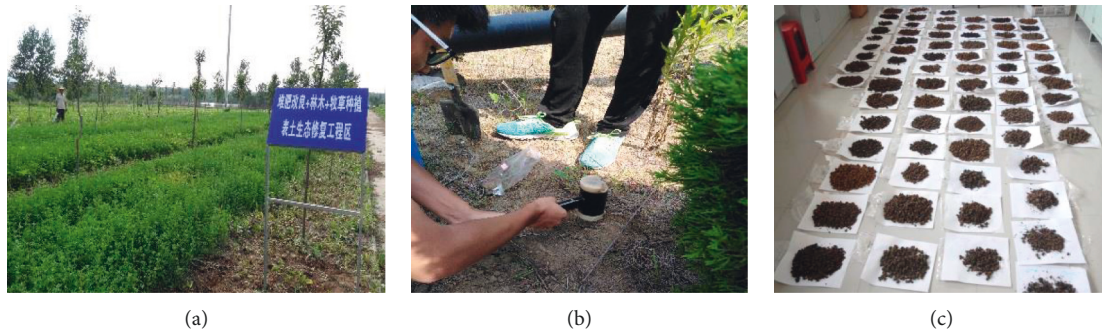


FIGURE 5: The collection and processing of soil samples. (a) Soil improvement test site. (b) Soil samples were collected with a ring knife. (c) Air-dry soil samples.

TABLE 5: Soil sample testing methods and standards.

Test indicators	Test methods	Reference standards
Soil moisture content	Drying method	T 0103-1993
pH	Potential method	GB7859-1987
Bulk density	Ring knife method	NY/T 1121.4-2006
Available nitrogen	Alkali-diffusion method	GB/T7849-1987
Available phosphorus	Ammonium fluoride-hydrochloric acid extraction	GB7853-1987
Available potassium	Ammonium acetate extraction-flame photometric method	GB7856-1987
Organic matter	Heavy acid oxidation-external heating method	NY/T1121.6-2006
Total nitrogen	CHN elemental analyzer	
Total phosphorus	Sodium hydroxide solution-molybdenum-antimony resistance colorimetric method	GB9837-1988
Total potassium	Acid solution-flame photometry	NY/T 87-1988

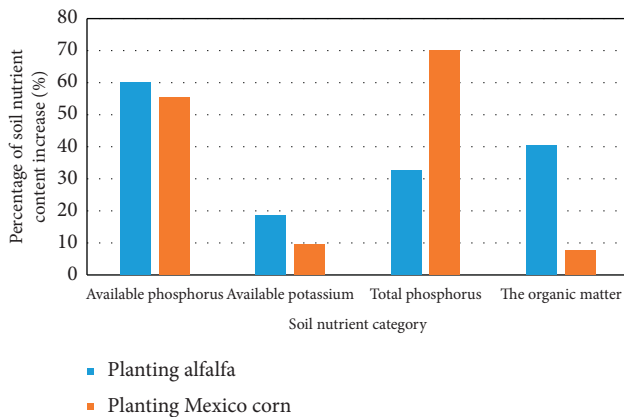


FIGURE 6: Physical and chemical indicators of the selected soils.

and we can conclude that planting alfalfa and Mexican corn in the reclamation area can effectively improve the soil quality.

3.2. Analysis of Soil Improvement Effect by Applying Compost.

According to Table 4, compost No.1 to No.4 are, respectively, applied in treatment groups, and alfalfa is planted in groups called Z1 to Z4, while Mexican corn is planted in groups called M1 to M4. The above 10 indexes are measured, respectively, and three indexes of available phosphorus, available potassium, and total phosphorus do have obvious increases. In order to study the influence of different experimental designs on the indexes of available phosphorus,

available potassium, and total phosphorus in reclaimed soil, Figure 7 is created to show the changes in available phosphorus, available potassium, and total phosphorus in groups Z1 to Z4 and M1 to M4.

(1) *Growing Alfalfa after Applying Compost.* As can be seen from the first three box plots of Figure 7, compared with the control group DZ, in the soil of the groups Z1 to Z4, the contents of available phosphorus increased to 123% from 45%, the contents of available potassium increased to 25% from 20%, and the contents of total phosphorus increased to 66% from 58% after applying four kinds of compost, respectively. A box plot uses its length to depict the distribution of a group of numeric data. According to the length of the first three box plots in Figure 7, the box of available phosphorus in Z1to Z4 is the longest, indicating that the content of available phosphorus changes most obviously in the soil after composting, and planting alfalfa after composting with alfalfa as the main raw material in reclaimed soil of the subsidence area can significantly improve the content of soil available phosphorus.

(2) *Growing Mexican Corn after Applying Compost.* In accordance with the last three box plots in Figure 7, compared with the group DM, after applying four kinds of compost, respectively, the contents of available phosphorus in M1to M4 increased to 114% from 22%, the contents of available potassium increased to 38% from 18%, and the contents of total phosphorus increased to 62% from 19%. According to the last three boxes in Figure 7, the available phosphorus,

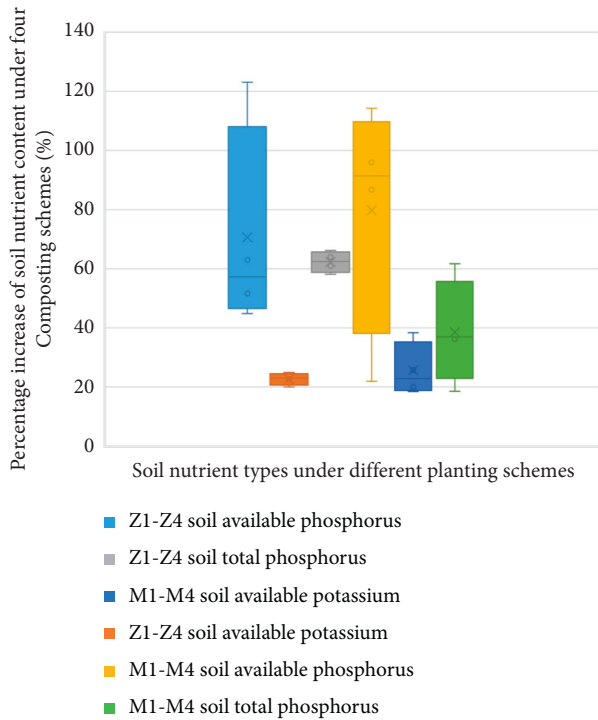


FIGURE 7: Nutrients changes in the soil with alfalfa and Mexican corn planted after compost improvement.

available potassium, and total phosphorus in the soil of M1–M4 are all longer, indicating that the contents of available phosphorus, available potassium, and total phosphorus have obvious changes after applying compost, and planting Mexican corn after applying compost with Cattail as the main raw material in the reclaimed soil of the subsidence area can obviously improve the contents of soil available phosphorus, available potassium, and total phosphorus.

(3) *Optimization of Compost Improvement Method.* The percentage increases in contents of available phosphorus, available potassium, and total phosphorus in the soil of Z1 to Z4 and of M1 to M4, as well as of DZ and DM, are shown in Figure 8. It can be seen from the figure that the groups with a faster increase in available phosphorus are Z1, M1, M2, and M3 with values of 123%, 114%, and 96%, respectively; the group with a faster increase in available potassium is M1 with the values of 38%; the groups with a faster increase in total phosphorus are Z3, Z4, and M1 with the value of 64%, 66%, and 62%.

At the same time, potassium, as a necessary element for plant growth, should be taken into consideration. Potassium plays an important role in biophysical and biochemical aspects, which is closely related to product transportation, energy conversion, and enzyme catalytic reaction in plants, and can obviously improve crop quality. In conclusion, the group with the best improvement effect of composting treatment is M1, in which planting Mexican corn after applying organic compost No. 1 has the best improvement effect on surface soil fertility in reclamation area.

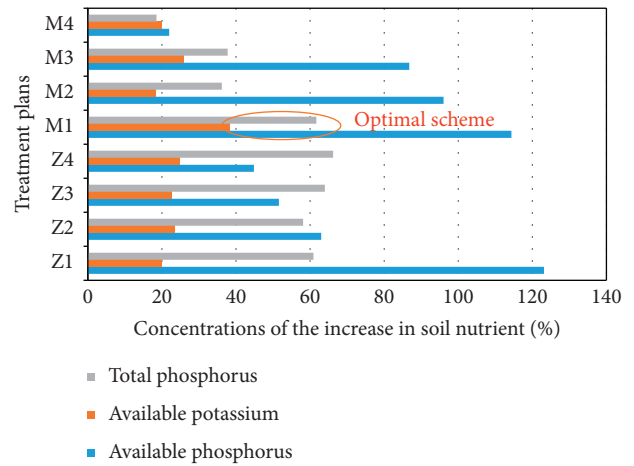


FIGURE 8: Fertility level of different treatment plans for compost improvement.

3.3. *Effect of Green Manure Improvement on Soil Fertility.* According to Table 4, the experiment on green manure improvement effect on treatment groups has been designed and conducted, and above 10 fertility indexes have been measured to draw the following conclusions.

After the nitrogen-fixing legume white vanilla clover is used as green manure to improve the soil in the reclamation area, compared with the control group CK, the contents of nitrate nitrogen, available phosphorus, available potassium, and total phosphorus in the surface soil of the group LZ increase by 155%, 58%, 30%, and 61%, respectively, while those of the group LM increase by 13%, 34%, 20%, and 29%. The test results are shown in Figure 9. In both groups LZ and LM, the rest of the fertility indexes are without obvious improvement. The results indicated that *Melilotus Baixiang* as green manure could significantly increase the contents of nitrate nitrogen, available phosphorus, available potassium, and total phosphorus in the surface soil of the reclamation area.

3.4. *Effect of Biomass Improvement Scheme on Soil Nutrients.* Through the above study, it is found that the three methods including growing grasses, applying compost, and green manure improvement on the reclaimed soil in the mining wasteland can improve the soil. Due to the barren soil in the mining waste area, the soil has a greater demand for available nutrients such as available phosphorus and available potassium. Therefore, the soil improvement schemes with more increase in available nutrients are selected to study the influence of soil improvement program on soil physical and chemical indexes. Therefore, six soil improvement schemes DZ, DM, Z1, M1, LZ, and LM are selected. Compared with the control scheme CK, the increased percentage of 10 soil physical and chemical indicators including water content, total nitrogen, ammonia nitrogen, nitrate nitrogen, available phosphorus, available potassium, total phosphorus, organic matter, pH, and conductivity is calculated. The calculation results are shown in Figure 10.

After the reclaimed soil of the mining wasteland is improved, the improvement effect is shown in Figure 10. LZ

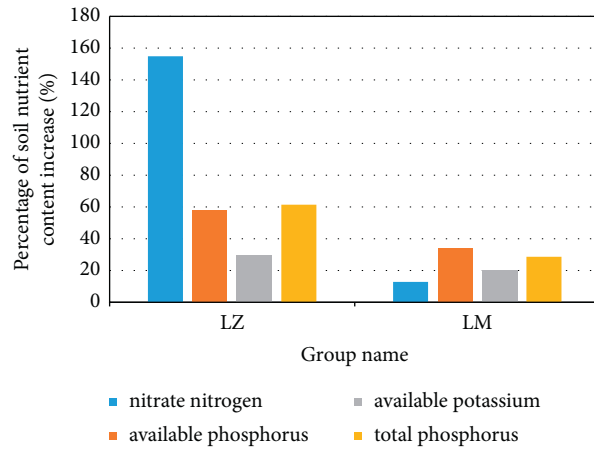
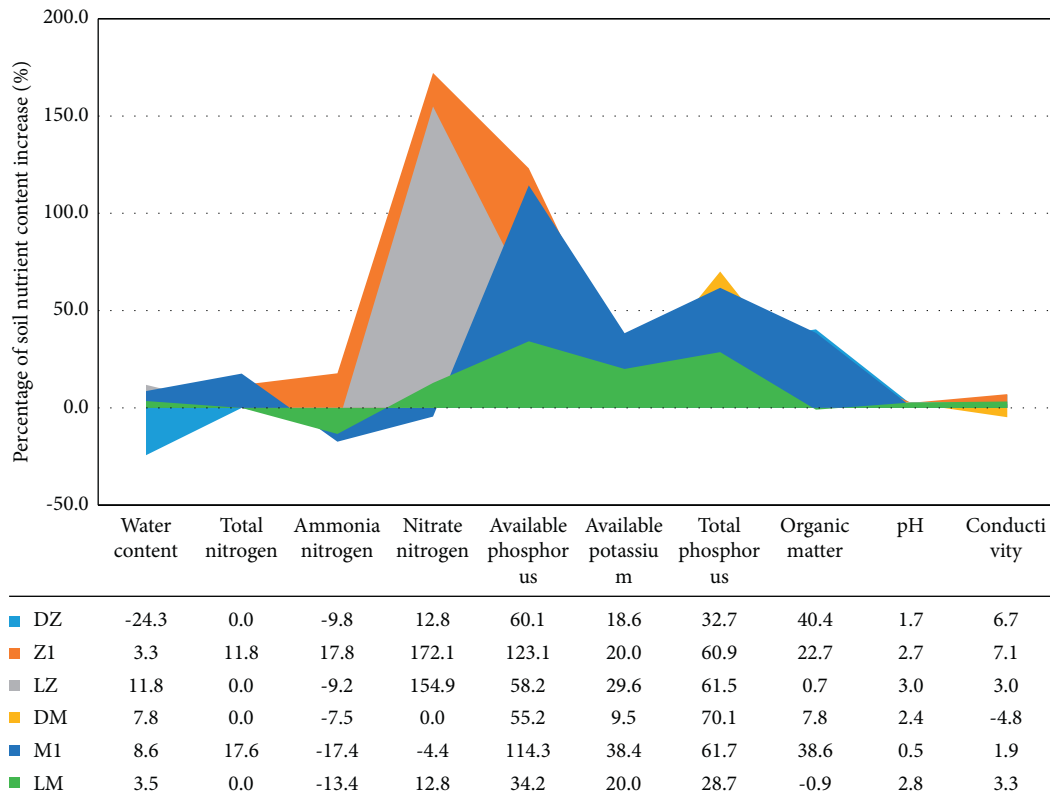


FIGURE 9: Fertility level of different treatment plans for green manure improvement.



Physical and chemical indicators of reclaimed soil

FIGURE 10: Effect of biomass improvement scheme on physical and chemical indexes of soil.

has the largest effect on water content, and pH, M1 has the largest effect on total nitrogen and available potassium. Z1 has the largest increasing effect on ammonia nitrogen, glutamic nitrogen, and available phosphorus in the soil, while DM has the largest increasing effect on total phosphorus in the soil. DZ has the greatest effect on improving organic matter and conductivity in soil. This is helpful in the selection of soil improvement schemes.

4. Discussion

The reclaimed soil of mining wasteland belonged to the artificial reconstruction soil, the soil structure had been completely changed, it was different from the original soil, and it was realized as the soil quality deteriorates and productivity decreases, and the main reason was that the physical and chemical properties of reclaimed soil had

changed greatly [8]. Biomass improvement methods applied to reclaimed soil could effectively restore the soil productivity of land [10]. In this study, the soil quality of reclaimed soil was effectively improved by planting alfalfa and Mexican corn. Cattail, an aquatic plant, was used as raw material to make organic compost and applied to reclaimed soil of mining wasteland. After planting Mexican corn, the content of available phosphorus, available potassium, and total potassium in the soil was significantly increased. White vanilla clover was made into green fertilizer and applied to reclaimed soil of mining wasteland, which significantly increased the contents of nitrate nitrogen, available phosphorus, available potassium, and total phosphorus in the surface soil of the reclamation area. Biomass improvement technology could improve the fertility level of coal mine reclamation soil in a short time. It is conducive to promoting the restoration of soil fertility of mining wasteland and realizing the sustainable development and utilization of plant resources and land resources. In general, these biomass improvement methods on reclaimed soil can provide a reference for land reclamation of mining wasteland.

5. Conclusion

- (1) After planting alfalfa and Mexican corn in the reclaimed soil, the contents of available phosphorus in the soil increase by 60% and 55%, respectively, the contents of available potassium increase by 19% and 10%, the contents of total phosphorus increase by 33% and 70%, and the contents of organic matter increase by 40% and 8%. Thus, we can conclude that planting alfalfa and Mexican corn in the reclaimed soil can effectively improve soil quality.
- (2) Cattail, a common aquatic plant, is the main raw material to make organic compost. After the compost is applied to reclaimed soil, planting alfalfa could significantly improve the soil's available phosphorus content, while planting Mexican corn could significantly improve the contents of the soil's available phosphorus, available potassium, and total phosphorus. The results show that the experimental design of the group M1 has the best effect on soil improvement, which means the improvement effect on the soil of the reclamation area with Mexican corn planted after applying organic compost No.1 is the best.
- (3) The surface soil is ploughed with nitrogen-fixing legume white vanilla clover as green manure. After soil improvement, alfalfa and Mexican corn are planted, respectively, and then, the contents of nitrate nitrogen in the soil increase by 155% and 13%, the contents of available phosphorus increase by 58% and 34%, the contents of available potassium increase by 30% and 20%, and the contents of total phosphorus increase by 61% and 29%. White vanilla clover could be used as good green manure to improve the reclaimed soil in mining wasteland.

Data Availability

Data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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