CHARACTERIZATION OF PLANT COMMUNITIES AND SOIL NUTRIENTS UNDER DIFFERENT RESTORATION MEASURES IN THE MANLALIANG COAL MINE DUMP IN ORDOS, CHINA

MA, Y. X. – YANG, G.* – WU, G. – GUO, X. Y. – QIAO, S.

College of Desert Control Science and Engineering, Inner Mongolia Agricultural University, Hohhot 010018, China

**Corresponding author*
e-mail: yg331@ 163.com

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Abstract. To study the effects of different restoration measures on the vegetation and soil of open-pit coal mine slopes, this paper takes the southern waste dump of Manlailiang coal mine as the experimental area, measures the plant community and soil nutrient indicators under three restoration measures: biological fence (BF), sand barrier (SB), and artificial strip sowing (AB). The impact of the three restoration measures on plant community characteristics and soil nutrient changes is analyzed, providing a theoretical and scientific foundation for ecological restoration of the waste dump. The research results indicate that (1) Compared with the control group, the soil organic matter was 12%-13% higher, the available potassium was 0.7%-1.4% higher, the alkali hydrolyzable nitrogen was 6.7%-14.44% higher than the sand barrier covering measure, and 33%-37.5% higher than the artificial strip sowing measure under the biological fence covering measure; (2) Under the biological fence coverage measures, the species diversity of the waste dump is superior to other measures; (3) The appearance of tall shrubs and semi shrubs in the sand barrier covering measures and biological fence covering measures indicates that the covering measures are more conducive to the growth of shrubs and semi shrubs.
Keywords: *opencut coal mine, slope repair, remediation measures, vegetation restoration, soil physicochemical properties*

Introduction

Coal remains a critical energy source globally, serving as the foundation of many modernization efforts (Longwell et al., 1995; Zedtwitz et al., 2003). China is one of the countries with the richest coal resources in the world, with large coal reserves, wide distribution, and complete coal types. Historically, coal resources have accounted for more than 70% of China's energy consumption (Xie et al., 2022; Pan et al., 2002). The development of coal resources is vital to China's economy, with open-pit mining widely adopted for its cost efficiency, high ore utilization, and safety (Wang et al., 2020; Qin et al., 2020). The coal production in the western region accounts for more than 60% of the national coal production. In western China, open-pit coal mining in arid and semi-arid regions often causes irreversible deformation of the original landscape. The substantial waste generated during mining exacerbates soil nutrient loss and erosion in the affected areas (Michalska et al., 2022; Li et al., 2020). The Ordos region, as a key area for coal mining in central and western China, has suffered severe ecological degradation in recent years due to large-scale open-pit mining, which has led to vegetation degradation, poor soil nutrient and erosion resistance in the mining waste dump and its surrounding areas (Sun et al., 2019; Mukhopadhyay et al., 2016; Yang et al., 2024). This ecological destruction poses a significant threat to the sustainable development of the region. Therefore, how to restore the waste dump to its original natural environment in the short term through artificial ecological restoration measures? This is one of the hot issues that urgently needs to be addressed to constrain the green and sustainable development of mining areas in China.

There is a close correlation between the ecological restoration effect of mining areas and environmental factors. Vegetation and soil are the two most basic elements in the process of mining area restoration, which affect the effectiveness and speed of mining area restoration (Huang et al., 2015). In recent years, the reclamation and ecological reconstruction of abandoned mining areas have become important research topics in the field of ecology. The soil in the waste dump is usually excavated earliest in the mining area, and after long-term accumulation, it becomes relatively hard and has a very low nutrient content (Qi et al., 2023). Fourie et al. (2007) proposed that the selection of land cover for reclamation is crucial, as it can promote the soil formation process of damaged soil. The main function of the cover system is to protect the environment, especially the groundwater system and soil. The different restoration measures of the waste dump have different impacts on the restoration and development of vegetation communities, and the restoration of vegetation communities is also crucial for the restoration of the ecological environment of the waste dump (Bradshaw et al., 1997; Ren et al., 2021; Chabukdhara et al., 2016). Grant et al. (2002) studied the ecological restoration of Australian mineral wastelands and addressed the survival rates and suitability of over a dozen local plant species for growth; Dowarah et al. (2009) conducted vegetation restoration and planting in the Tirap coal mine area in 2009, selecting herbaceous monocotyledonous plants with fibrous roots and shrubs, and sowing them in soil damaged areas to accelerate the process of mine coverage. Lesica et al. (1999) also demonstrated in their research on ecological genetics and vegetation restoration that appropriate vegetation configuration is a key focus of ecological restoration.

At present, most existing research has focused on the local application and effectiveness evaluation of individual recovery techniques, but there is relatively little research on the application of different recovery measures in complex environments. Manlailiang Coal Mine is located in the transitional zone between arid and semi-arid, with extreme climate and facing harsh environments such as prolonged drought, frequent sandstorms, and high temperatures. The mining waste dump is mainly formed by the accumulation of abandoned soil, rocks, and waste materials generated during the mining process. The soil is barren, plants are scarce, and soil erosion is severe. This article takes the southern waste dump of Manlailiang Coal Mine as the experimental area, and adopts three restoration measures: biological fence covering (BF), sand barrier covering (SB), and artificial strip sowing (AB) to repair the slope. The impact of the three different restoration measures on plant community characteristics and soil nutrient changes is analyzed, providing theoretical basis and scientific basis for the ecological restoration of the waste dump. This study will provide theoretical basis and practical guidance for future large-scale ecological restoration projects, especially in the context of addressing global climate change and intensified human activities, to promote broader land and ecosystem restoration work.

Experiments and methods

Overview of the study area

The experimental area is located at the Manlailiang open-pit coal mine in Nalintaohai Town, Ejin Horo Banner, Ordos City, Inner Mongolia Autonomous Region. The coal

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mine is situated in the northeast of the Ordos Plateau, with significant geographical features of the Loess Plateau and widespread distribution of low hills. The geographical coordinates are between 38°56′and 39 ° 49′ north latitude and 108°58′and 110°25′east longitude. The climate belongs to a typical temperate continental monsoon climate, with low precipitation, high evaporation, and dry climate. The annual average precipitation is 320 mm, with precipitation concentrated in July and August each year. The regional soil is sandy loam soil, and the vegetation types are mainly sandy vegetation and meadow vegetation.

Sample plot setting and sample collection

The southern waste dump with a slope length of 30 m and a gradient of 30 degrees was selected as the experimental area in Manlailiang Coal Mine. Three restoration measures, including biological fence coverage (BF), sand barrier coverage (SB), and artificial strip sowing (AS), were adopted to repair bare slopes without human intervention, and the same plants were planted. These three measures have shown good results in the preliminary experiments. Biological fences are suitable for the initial stage of ecological restoration, sand barrier covering is suitable for preventing wind and sand erosion, and artificial strip sowing is suitable for rapid vegetation restoration, especially in areas with soil erosion. Meanwhile, undisturbed grasslands around the mining area were selected as controls (CK). The three specific recovery measures are:

1. Biological fence coverage (BF): Using branches and stems of plants such as lemon, sea buckthorn, and sand willow as biological materials, a 20 × 20 cm grid fence is woven, with each fence measuring 5 × 5 m, laid flat on the slope of the waste dump, and fixed by piles.
2. Sand barrier coverage (SB): Insert the branches of Salix into the soil, bury them at a depth of 20 cm, form a diamond shape, and vertically insert them into the slope of the dumping site.
3. Artificial strip sowing (AS): Artificially streak seeds within a distance of 50 cm.

Sampling will begin in mid August 2023, with 3 experimental plots for each measure, totaling 9 plots, each measuring 25 m^2 (5 × 5 m). The plots for the 3 measures will be randomly distributed and divided into three heights: uphill (PS), mid slope (PZ), and downhill (PX). All plots were restored to their natural state without any human intervention.

Vegetation community survey: Conduct a survey of each community using a sampling method, with a sample plot of 1 m × 1 m. Randomly sample within the community, with 3 sampling points set up in each community.

Soil sampling: Multi point mixed sampling method is used for on slope (PS), in slope (PZ), and under slope (PX) to remove surface vegetation and cover, and mixed samples are taken in different soil layers. And use soil drilling method to collect fresh soil samples from three soil layers at depths of 0-10 cm, 10-20 cm, and 20-30 cm at various points. The fresh soil collected from each sampling point was divided into two parts and placed in polyethylene sealed bags, which were brought back to the laboratory. The plant roots and stones in the fresh soil were removed in the laboratory, and then sieved through a 0.15 mm soil sample sieve to determine soil nutrient indicators. Set three repetitions during sampling.

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Determination of soil nutrients

Organic matter is measured using potassium dichromate volumetric method external heating method; Alkaline nitrogen is determined by alkaline hydrolysis diffusion method; Available phosphorus is determined by spectrophotometry; Available potassium was extracted using NH_4OAc and determined by flame photometry.

Calculation of aboveground biomass of plants

Calculation of aboveground biomass of plants: During sampling, use scissors to tightly adhere to the ground, select all aboveground plants in the sample plot, pack them in self-sealing bags, send them to the laboratory, dry them to constant weight at 105℃, and weigh them with an electronic scale with an accuracy of 0.01 g.

Data processing and analysis

Important value formula:

$$\text{Importance value} = (\text{relative abundance} + \text{relative frequency} + \text{relative height} + \text{relative coverage}) / 4 \quad \text{(Eq.1)}$$

Margalef richness index (R) formula:

$$D = S - 1 / \ln N \quad \text{(Eq.2)}$$

Shannon Wiener diversity index (H) formula:

$$H = -\sum_{i=1}^{S} (P_i \times \ln P_i) \quad \text{(Eq.3)}$$

Pielou's uniformity index (E) formula:

$$E = H / \ln S \quad \text{(Eq.4)}$$

Simpson's index (D) formula:

$$C = \sum_{i=1}^{S} N_i (N_i - 1) / N(N - 1) \quad \text{(Eq.5)}$$

In the formula, Pi is the frequency, Pi = Ni/N, S is the number of groups, Ni is the number of individuals in the i-th group, N is the total number of individuals in all groups, and the number of individuals in i is xi, i = 1, 2, 3... m.

Results and analysis

Analysis of plant importance values under different measures

There are 46 species of plants belonging to 36 genera and 14 families on the slope of the waste dump under different restoration measures. Among these plants, there are 12 species of *Poaceae*, 11 species of legumes, 7 species of *Asteraceae*, 4 species of *Chenopodiaceae*, 2 species of *Lamiaceae*, and 2 species of *Brassicaceae*; There is only

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one species in the families *Polygonaceae*, *Ephedra*, *Portulaceae*, *Geraniaceae*, *Amaranthaceae*, *Convolvulaceae*, *Ulmaceae*, and *Iridaceae*. Among them, BF measures have the best effect and the richest vegetation composition, with a total of 38 species. There are relatively few vegetation types in SB and AS measures, totaling 29 species. Among them, only *Brassica rapa* var. Oleifera, a biennial herbaceous plant, shows a phenomenon of annual replacement, while Amaranthus tricolor, *Setaria viridis*, *Lepidium apetalum*, and other biennial plants dominate. The importance value of *Amaranthus tricolor* under SW measures is 0.584, the importance values of *Setaria viridis* under BF measures, SB measures, and AS measures are 0.163, 0.208, and 0.157, respectively, and the importance value of *Lepidium apetalum* under BF measures is 0.222. Perennial plants are mainly represented by *Elymus dahuricus*, *Medicago falcata*, and *Leymus chinensis*. The importance values of *Elymus dahuricus* under BF, SB, and AS measures are 0.214, 0.117, and 0.094, respectively. The importance values of *Medicago fallata* under BF, SB, and AS measures are 0.176, 0.089, and 0.264, respectively. The importance values of *Leymus chinensis* under BF and SB measures are 0.538 and 0.263, respectively. Shrubs and semi shrubs are mainly dominated by *Caragana microphylla* and *Caragana korshinski*. The importance values of *Caragana microphylla* under BF and SB measures are 0.174 and 0.13, respectively, while the importance values of *Caragana korshinski* under BF and SB measures are 0.137 and 0.203, respectively (*Table 1*).

Table 1. *Changes in plant importance values under different restoration measures*

Species	Different recovery measures			
	BF	**SB**	**AS**	**CK**
Teloxys aristata	0.052			
Artemisia sieversiana	0.158	0.182	0.036	0.086
Lepidium apetalum	0.222			
Setaria viridis	0.163	0.208	0.157	0.197
Chloris virgata	0.114	0.093	0.049	0.231
Eragrostis minor	0.064	0.069	0.06	0.08
Oxybasis glauca	0.076			0.003
Fagopyrum tataricum	0.064			
Artemisia scoparia	0.046	0.063	0.032	0.062
Kali collinum	0.061	0.145	0.091	0.28
Neopallasia pectinata	0.113			0.071
Panicum miliaceum	0.057			
Dracocephalum moldavica	0.073	0.177	0.038	
Amaranthus tricolor	0.584			
Corispermum mongolicum	0.086	0.098	0.062	0.101
Portulaca oleracea	0.092			
Schizonepeta tenuifolia	0.072	0.124		
Melilotus officinalis				
Agriophyllum squarrosum				
Avena chinensis				
Brassica rapa var. oleifera	0.243	0.151		0.212
Aster altaicus	0.046		0.054	
Artemisia argyi	0.081		0.037	

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Agropyron cristatum	0.099	0.068		0.106
Cleistogenes squarrosa	0.057	0.079	0.044	0.15
Elymus nutans	0.048		0.214	0.124
Stipa grandis	0.129	0.1		0.08
Astragalus membranaceus	0.1		0.089	
Convolvulus ammannii	0.066			
Artemisia capillaris	0.052		0.063	0.052
Leymus chinensis	0.538	0.263		0.041
Iris tenuifolin	0.035			
Gueldenstaedtia verna	0.051		0.017	
Erodium stephanianum	0.049		0.055	
Ephedra sinica	0.07		0.071	
Medicago ruthenica		0.042	0.106	
Astragalus melilotoides	0.045	0.127	0.105	0.172
Medicago falcata	0.176	0.089	0.264	0.207
Elymus dahuricus	0.214	0.117	0.094	0.153
Astragalus laxmannii	0.107	0.097	0.086	0.142
Artemisia desertorum				
Bromus inermis	0.037	0.09	0.08	0.213
Poa sphondylodes				
Medicago sativa	0.197	0.097	0.075	0.048
Lespedeza davurica	0.1	0.07		
Bassia prostrata				
Caragana korshinski	0.137	0.203		0.303
Caragana microphylla	0.174	0.13		0.125
Corethrodendron fruticosum	0.071	0.106		0.177
Ulmus pumila	0.36			

Biological fence coverage (BF). Sand barrier coverage (SB). Artificial strip sowing (AS). Same as below

Analysis of plant community life forms under different measures

The life form composition of vegetation under three different measures is basically the same, with herbaceous types being the main type, accounting for more than 80%, and perennial herbaceous plants being the majority, especially under the BF measure where perennial herbaceous plants account for 50%. The number of trees is very small, accounting for 2.7% in BF measures. Among the three different measures, the proportion of perennial herbaceous plants under BF measure is relatively large, which is about 5.2%, 8.6%, and 3.3% higher than that under AS measure, SB measure, and CK measure, respectively. The proportion of shrubs and semi shrubs under SB measures is higher than the other two measures, accounting for 20.7%. Among them, only trees appeared in the BF measure, while the other two measures did not (*Fig. 1*).

Analysis of plant community biomass under different measures

Among different recovery measures, the aboveground biomass of PZ height under BF measure was more than 50% higher than the other two measures and the control

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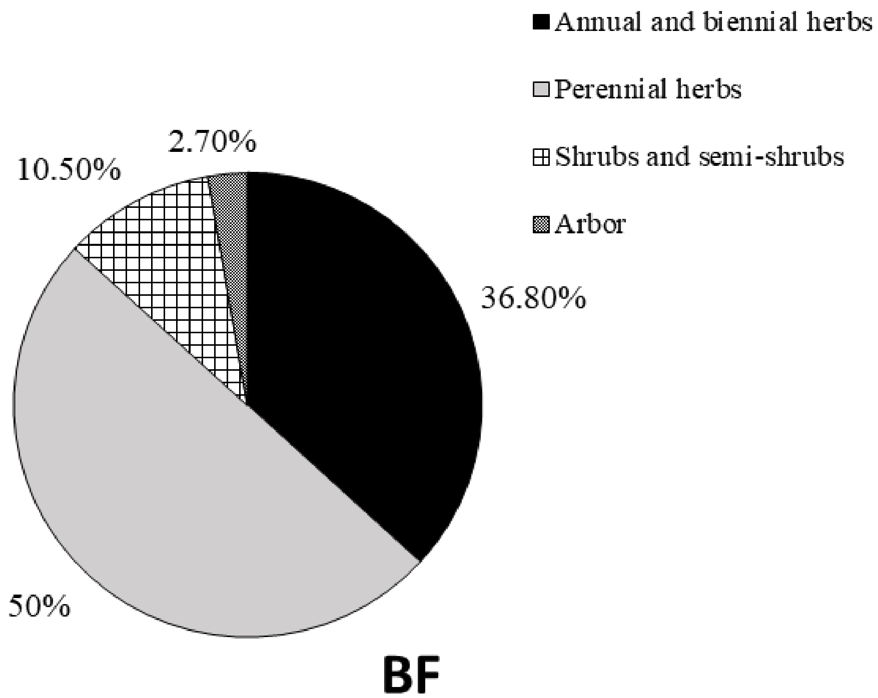
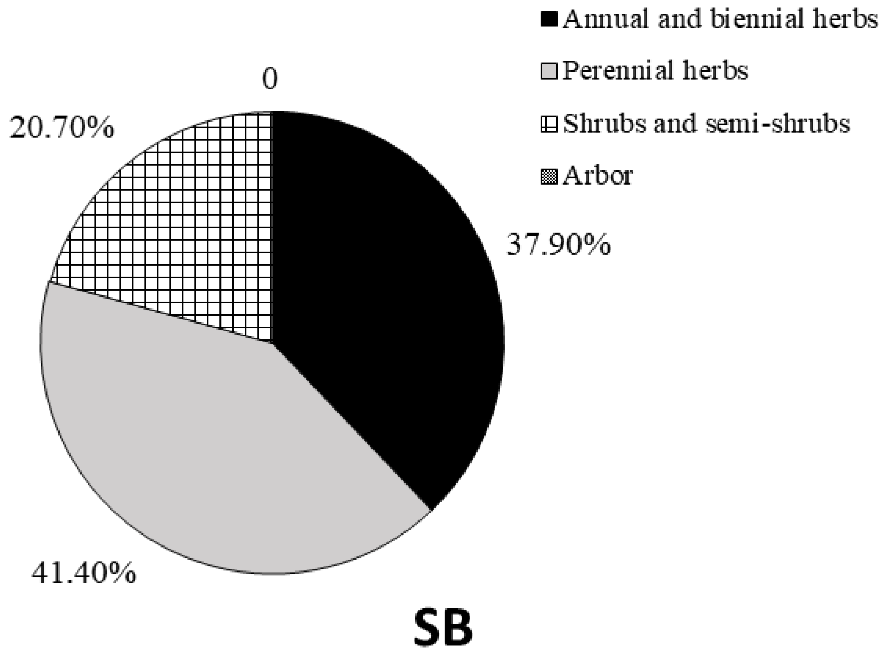
group. The aboveground biomass of PX height under BF measures was about 34.3%, 12.7%, and 54.3% higher than that under SB measures, AS measures, and CK measures, respectively. Among the same measures, the biomass of the PZ height community under the BF measure was 317 g/m^2, slightly higher than the 315 g/m^2 under the PX measure. There was no significant difference in aboveground biomass among the three different heights under the BF measure; Under SB measures, the aboveground biomass at PS height was the highest, about 56.2% and 80.2% higher than that at PZ and PX heights, respectively; Under AS measures, the aboveground biomass of PX height community is 275 g/m^2, which is about 68.4% and 58.1% higher than PS height and PZ height, respectively. Compared with the three measures, BF measure is superior to SB measure and AS measure in community biomass recovery (*Fig. 2*).





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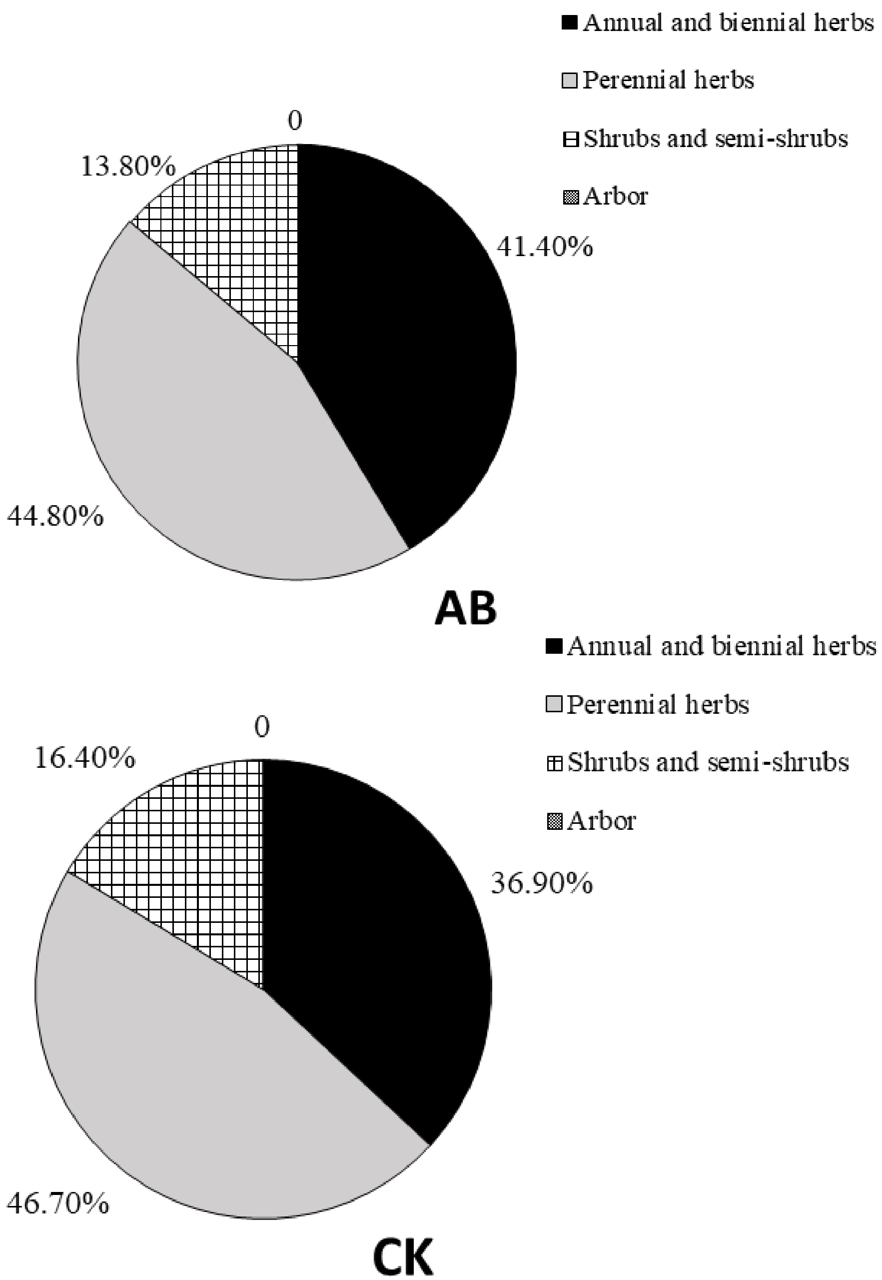

Figure 1. *Changes in vegetation lifestyle under different restoration measures*

Analysis of plant species diversity under different measures

Among different restoration measures, the plant community diversity at PZ and PX heights under AS measures was not as good as the other two restoration measures; The recovery of PZ height under BF measures is poor, and the species diversity is lower than that under SB measures (*Fig. 3*). Among the same measures, the BF measure has the highest species richness of 1.6 at PS height, with a relatively uniform distribution of plants and better recovery effect than the other two heights. Under BF measures, the height of PS is higher than that of PZ in Shannon and Margalef indices, with increases of 12.3% and 88.9% respectively. In SB measurement, the Pielou index of PZ height is 1.08 times that of PX height, while the Margalef index is 0.75 times that of PX height.

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From various indicators, it can be seen that under AS measures, the plant richness at PS height is relatively high, and the plant distribution is relatively uniform. The ecological functions of dominant plants at PX height are prominent, and the species richness is higher than that at PZ height, with the highest number of species among the three different heights. Compared to the AS measure, the BF and SB coverage measures have better species diversity.

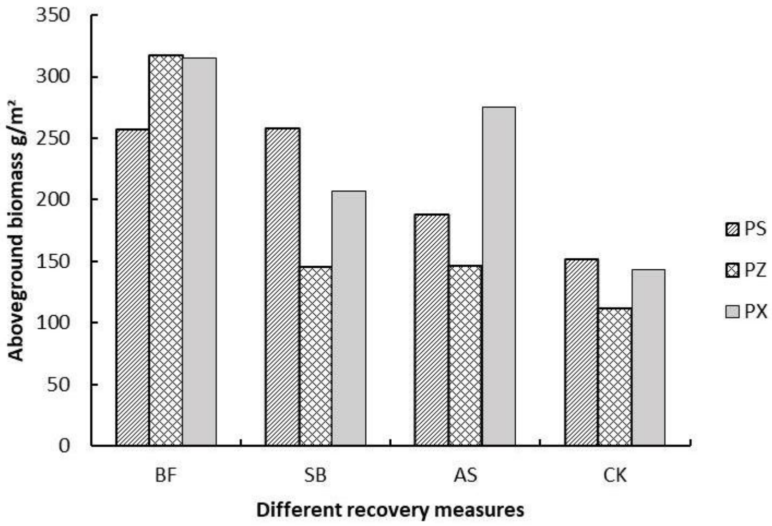

Figure 2. *Changes in aboveground biomass of plants under different restoration measures*

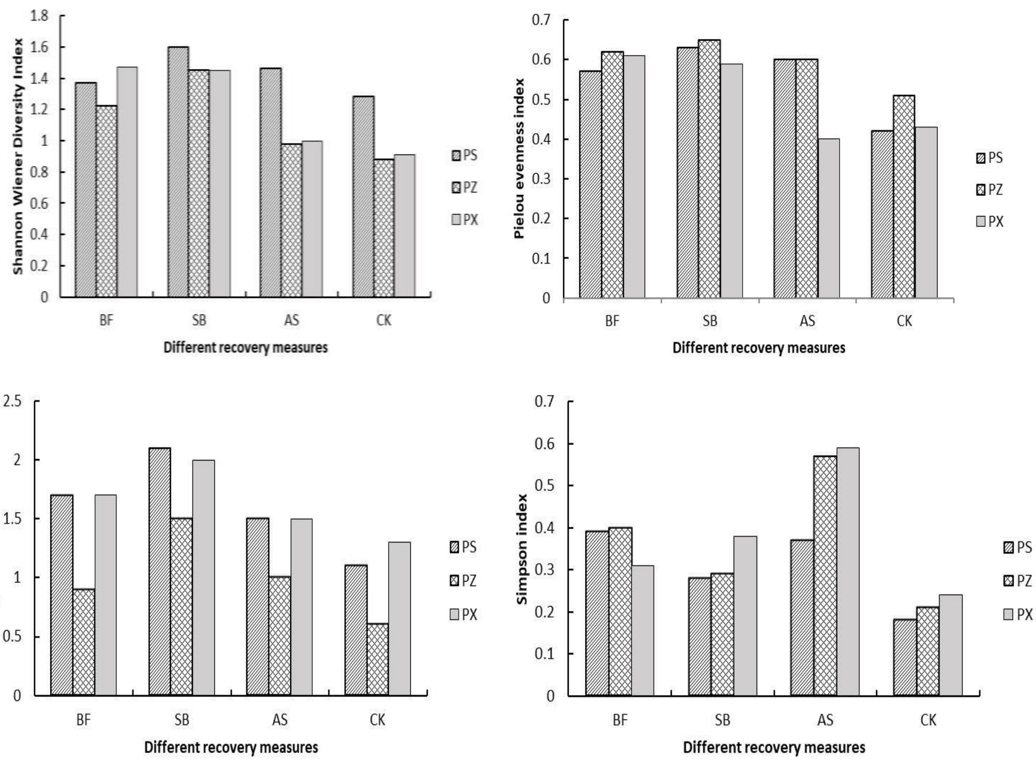

Figure 3. *Changes in plant community diversity index under different restoration measures. Slope Upper (PS), Slope Middle (PZ), Slope Lower (PX). Same as below*

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Changes in soil organic matter content under different measures

Among different restoration measures, the organic matter content in different soil depths under BF measures is basically the same, with a fluctuation of no more than 1.2%. Compared with the other two measures, the organic matter content in different soil depths under BF measures is relatively higher (*Fig. 4*). Under SB measures, the organic matter content in soil depths of 0-10 cm and 20-30 cm is basically the same, with 10-20 cm having a lower organic matter content than 0-10 cm and 20-30 cm by about 31.6%. The organic matter content in the soil depth of 0-10 cm under AS measures is significantly lower than that of other measures with the same soil depth, and is 47.1% and 49.9% lower than that of the soil depth of 10-20 cm and 20-30 cm under AS measures. Among the three measures, the organic matter content in the 10-20 cm soil depth under SB measure and the 0-10 cm soil depth under AS measure decreased compared to CK, while the organic matter content in the three different soil depths under BF measure increased compared to CK. This indicates that BF measures are beneficial for increasing soil organic matter content after soil improvement, and the effect is better than SB and AS measures.

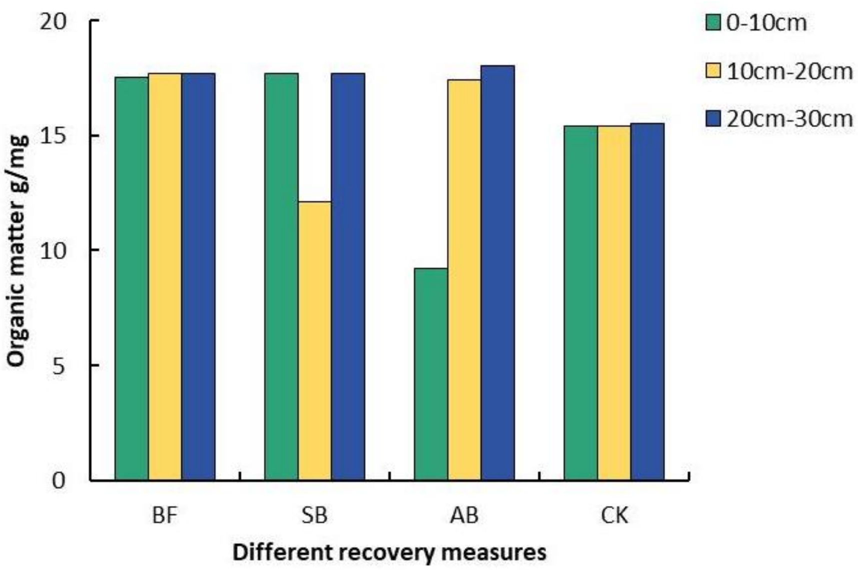

Figure 4. *Changes in soil organic matter content under different restoration measures*

Changes in soil available potassium content under different measures

As shown in *Figure 5*, the soil available potassium content is highest under the BF measure among different restoration measures, and the available potassium content is basically the same at different soil depths under the BF measure, with a fluctuation of no more than 1.4%. The content of available potassium in different soil depths under SB measures is at a moderate level among the three measures and the content is basically the same. The content of available potassium in soil depths of 0-10 cm and 10-20 cm under AS measures is about 34.3% and 28.1% lower than that under BF measures, and about 28% and 20% lower than that under SB measures, indicating a significant difference in content. Among the three measures, the content of available potassium in soil depths of 0-10 cm and 10-20 cm under BF measures slightly increased compared to CK, with an increase of about 0.7% and 1.1%, respectively. Under SB measures, the

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height of available potassium content in different soil depths has not yet reached the height of available potassium content in CK soil, with a difference of 8.1%-10.97% compared to CK. Under AS measures, the content of available potassium in different soil depths was significantly lower than that in CK, especially in the 0-10 cm soil depth where the difference in available potassium content was 33.8%. This indicates that BF measures are beneficial for increasing soil available potassium content after soil improvement, and the effect is better than SB and AS measures.

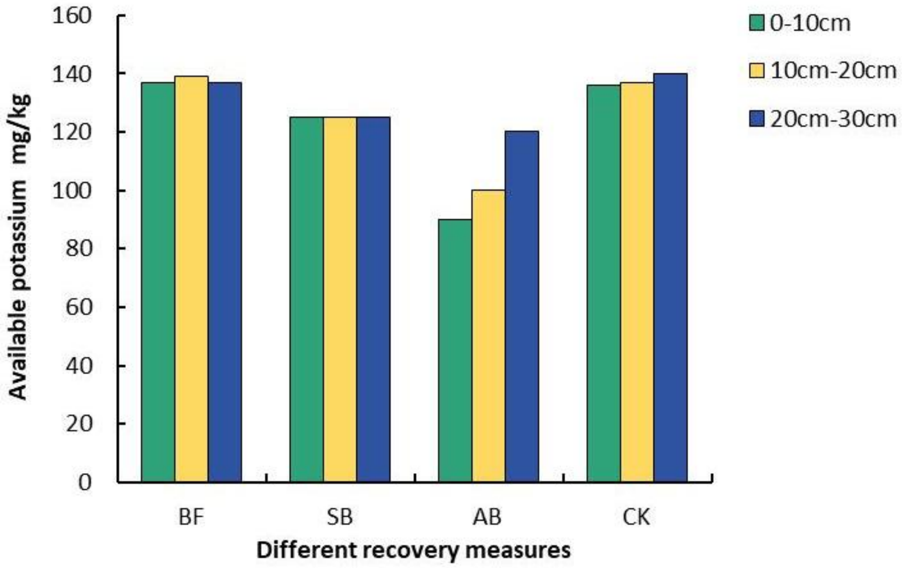

Figure 5. *Changes in soil available potassium content under different restoration measures*

Changes in soil available phosphorus content under different measures

Among different restoration measures, the content of available phosphorus in soil depths of 20-30 cm under BF measures was lower than that in soil depths of 0-10 cm and 10-20 cm, which were 42.8% and 41.4%, respectively. The significant difference in content indicates that the improvement effect of BF measures on soil available phosphorus content decreases with increasing soil depth. The available phosphorus content in the 0-10 cm soil depth under SB measures is lower than that under BF and AS measures at the same soil depth, by about 45.6% and 42.9%, respectively, indicating that SB measures have a poorer effect on improving the available phosphorus content in surface soil compared to the other two measures. Under AS measures, as soil depth increases, the content of available phosphorus significantly increases. The content of available phosphorus in soil depth of 20-30 cm is about 36.4% higher than that in surface soil depth of 0-10 cm. Among the three measures, the content of available phosphorus in soil depths of 0-10 cm and 10-20 cm under BF measures was significantly higher than that under CK, with an increase of about 55.6% and 50.3%, respectively. Under SB measures, only the available potassium content in soil depths of 10-20 cm is higher than that in CK. Under the AS measure, the available potassium content in each soil depth was significantly higher than that of the CK, and overall, the available phosphorus content in each soil depth was higher than the other two measures, indicating that the AS measure is beneficial for soil improvement and has a better effect than the BF and SB measures (*Fig. 6*).

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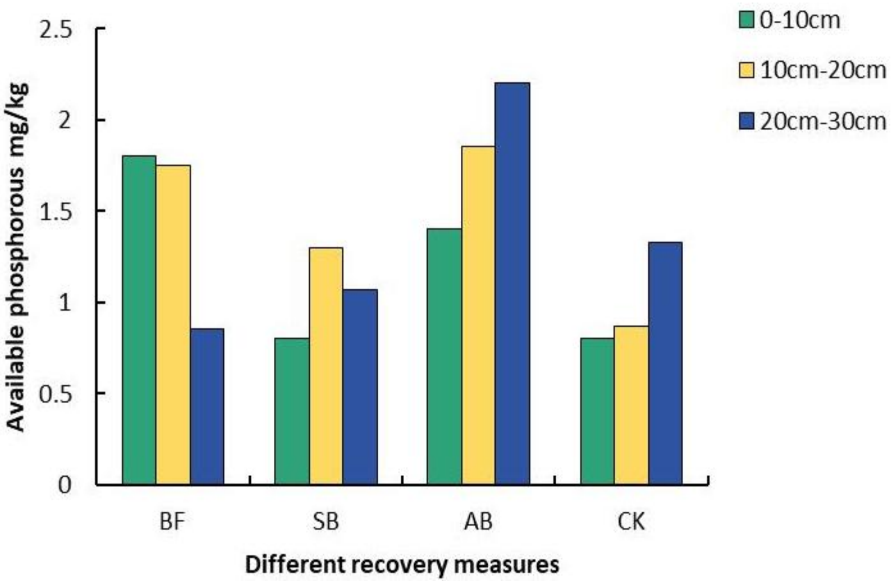

Figure 6. *Changes in soil available phosphorus content under different restoration measures*

Changes in soil alkaline nitrogen content under different measures

Among different restoration measures, the alkaline nitrogen content in different soil depths under BF measures was significantly higher than that under AS measures, and slightly higher than that under SB measures. As the soil depth increases, the soil alkaline nitrogen content under BF measures is about 37.5%, 34%, and 33% higher than that under AS measures, and about 6.7%, 13.6%, and 14.4% higher than that under SB measures. Under SB measures, the alkaline nitrogen content in soil depths of 0-10 cm is about 6.5% and 6.8% higher than that in soil depths of 10-20 cm and 20-30 cm, respectively. The alkaline nitrogen content in different soil depths under AS measures was significantly lower than the other two measures (*Fig. 7*). The difference in alkaline nitrogen content between different soil depths under BF measures and CK was the smallest, with differences of 2.5%, 9.3%, and 2.2% in alkaline nitrogen content between soil depths of 0-10 cm, 10-20 cm, and 20-30 cm, respectively. The difference in alkaline nitrogen content between different soil depths and CK under SB and AS measures is greater than this value, indicating that BF measures are beneficial for soil improvement and increase in alkaline nitrogen content.

Discussion

The impact of different measures on plant community biomass and diversity

Vegetation restoration is one of the key guarantee works for ecological restoration of abandoned coal mines. In terms of ecological restoration research, special attention is paid to the species composition, diversity changes, and differences comparison in the vegetation restoration process (Nagaraja et al., 2005; Tilman et al., 1994; Ruiz-Jaén et al., 2005; Verma et al., 2005). Through the analysis of plant community biomass under different measures, it was found that in the BF measure, the aboveground biomass of the plant community was higher than the other two measures, especially at the PZ height where the aboveground biomass was the highest. This is because at this height,

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the growth environment of plants is relatively stable, the probability of soil erosion and other problems is low, and the vegetation is relatively high, resulting in better soil moisture preservation. Under SB and AS measures, the aboveground biomass at PZ height was lower than at other heights, possibly due to severe soil erosion on the slope and limited nutrient absorption by plant roots. The restoration effect of BF and SB measures is better than that of AS measures, because reducing further erosion losses through coverage and other methods can promote the increase of aboveground biomass, which is conducive to accumulating good water and heat conditions for community succession (Bradshaw et al., 2020). The appearance of tall shrubs and semi shrubs in the coverage measures indicates that the coverage measures are more conducive to the growth of shrubs and semi shrubs, and the soil environment is more suitable for plant rooting. For the analysis of plant community biodiversity, different measures lead to different species diversity (Martínez et al., 2022). The comparison results under the same measure show that among different measures, the plant community diversity at PZ height is the worst, while PS height is also better than PZ height. This may be because PS height is closer to the top plane, soil is more compacted, and water is not easily lost. At the height of PZ, soil erosion is more severe, resulting in the loss of soil nutrients. However, the impact on shrubs with well-developed root systems is relatively small, leading to a phenomenon of lower species richness in the middle and lower slopes, while higher species richness is observed on the upper slopes (Zhang et al., 2010). In arid and semi-arid regions, especially in mining areas in Australia, natural restoration and biodiversity conservation methods are also used to replace simple artificial irrigation and fertilization, in order to achieve more sustainable ecological restoration benefits. In addition, in areas with steep slopes, more refined restoration measures may be needed, or more drought tolerant and adaptable plant species may be selected. The selection of restoration techniques (such as planting, fertilization, covering, etc.) may also have different impacts on species diversity. For example, planting a single plant species may lead to a decrease in species diversity, while a diverse plant configuration can help restore ecological functions and enhance species symbiotic relationships (Pimentel et al., 2013).

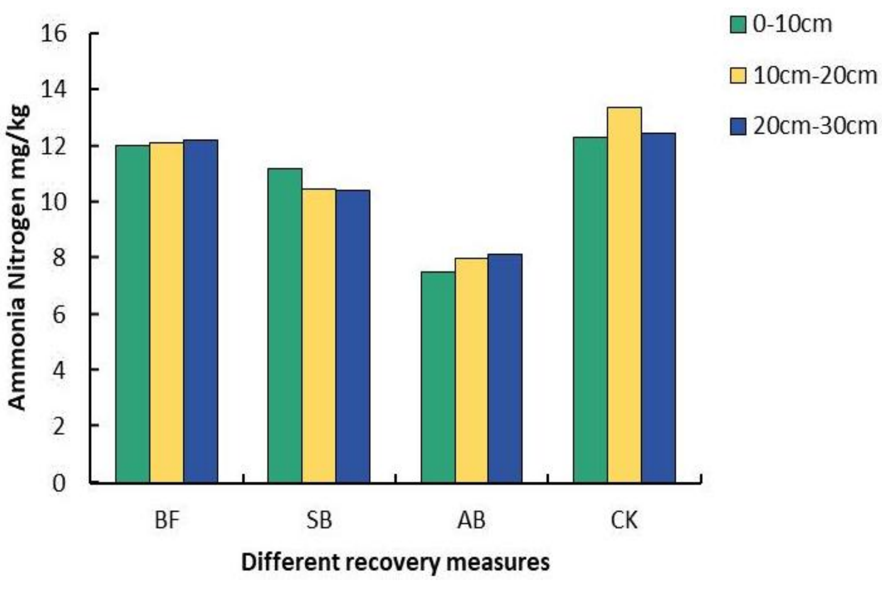

Figure 7. *Changes in soil alkaline nitrogen content under different restoration measures*

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The impact of different measures on soil nutrients

Through the analysis of soil nutrients under different measures, it was found that among different measures, BF coverage measures have relatively high levels of various nutrients in the soil. BF measures can increase soil nutrient content, increase organic matter, accelerate soil improvement effects, and promote plant colonization and growth, which is consistent with the research results of Zhao et al. (2010). Soil organic matter plays an important role in improving soil physical and chemical properties and ensuring normal plant growth, and is known as the "soil nutrient storage reservoir" (Minasny et al., 2017). In the determination of soil organic matter content, the organic matter content in the 0-10 cm soil depth of AS measure was 52.6% lower than that of BF measure and 52% lower than that of SB measure. This may be due to the slow recovery of surface soil organic matter content caused by AS measure. In the determination of soil available potassium content, similar to the results of soil organic matter content determination, the BF measure had the highest soil available potassium content, while the AS measure had the lowest soil available potassium content, and the distribution of available potassium content was uneven at different soil depths. Under the SB measure, the content of available potassium is evenly distributed in different soil depths, and under all three measures, the content of available potassium is between 90-140 mg/kg. In the determination of soil available phosphorus content, the AS measures showed higher available phosphorus content in soil depths of 10-20 cm and 20-30 cm compared to the other two measures, indicating that the AS measures may have a better effect on improving soil phosphorus content. In the determination of soil alkaline nitrogen content, the alkaline nitrogen content was highest under BF measures and lowest under AS measures. The alkaline nitrogen content under BF measures was 4.02-4.5 mg/kg higher than that under AS measures, with a difference of approximately 32%-37.5%. Under the BF and AS measures, the alkaline nitrogen content increases with soil depth, which is consistent with the research results of Li et al. (2019). However, under the SB measures, the alkaline nitrogen content decreased with increasing soil depth, suggesting that differences in research results may be due to variations in study areas. In areas with similar degradation issues, restoration measures need to be optimized and adjusted according to the degree of degradation and differences in ecological restoration response. In addition, vegetation communities and soil characteristics are influenced by a combination of climate environment, soil heterogeneity, and other factors. When formulating specific restoration strategies, the characteristics of degradation levels in different regions should be comprehensively considered, and restoration measures should be adjusted according to the restoration time and stage. For example, in areas with more severe soil erosion, measures such as replanting + fertilization, replanting + water retaining agents can be implemented.

Conclusion

(1) Under the three measures, the organic matter in the soil of the Manlailiang coal mine waste dump under the biological fence coverage measure was 12%-13% higher than the control group, the available potassium was 0.7%-1.4% higher, the alkaline nitrogen was 6.7%-14.44% higher than that under the sand barrier coverage measure, and 33%-37.5% higher than that under the artificial strip sowing measure. This indicates that the biological fence coverage measure has the best effect on increasing soil nutrient content, the sand barrier coverage measure is in the middle, and the

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artificial strip sowing measure is the worst. However, the artificial strip sowing measure had a better effect on the increase of soil available phosphorus content than the other two measures. The available phosphorus content in 10-20 cm and 20-30 cm soil was 5.4% and 61.4% higher than that under the biological fence covering measure, respectively; Compared with sand barrier coverage measures, the soil available phosphorus content increased by 42.9%, 5.4%, and 51.4% with increasing soil depth.

(2) Under the biological fence covering measures, the species diversity of the waste dump is better than other measures, which is conducive to vegetation planting and growth. However, the overall species diversity of the artificial strip sowing measures is not as good as the two covering measures, indicating that the covering measures have a more significant effect on plant community succession after soil improvement.

(3) The appearance of tall shrubs and semi shrubs in the sand barrier covering measures and biological fence covering measures indicates that the covering measures are more conducive to the growth of shrubs and semi shrubs. After soil improvement, the soil environment is more suitable for plant rooting.

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