Experimental Study on Vegetation Restoration of Abandoned Land in Desert Steppe Nonferrous Metal Mine

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Abstract. Taking the mine dump in nonferrous metal mine as the research object in desert steppe Inner Mongolia, according to the artificial remodeling of the landforms and the characteristics of water and soil erosion, the vegetation restoration model tests on the dumping site were carried out. The ecological effects of four vegetation restoration measures on soil and water storage were analyzed which including shrubs, shrub-grass, grass and natural restoration of vegetation. The research results showed that compared with the natural restoration plant community, the soil surface water content of the three planting restoration measures increased obviously, the soil organic matter content increased but the change difference was not obvious. The vegetation coverage of shrub-grass was 67%, and the aboveground biomass was 132 g/m2. The vegetation restoration measure of shrub-grass had stronger wind-proof and soil-fixing ability than other measures, the vegetation coverage reaches 67% and the above-ground biomass is 132 g/m2. Efficacy evaluation was carried out by the grey correlation method, and Comprehensive benefit of shrubs, shrub-grass and grass all reached higher value. The most comprehensive benefit was the shrub-grass measure, which reached 0.68, and the smallest was shrubs measure also reached 0.60. Three measures cloud be applied to the vegetation restoration of desert steppe metal mining areas, and shrub-grass measure was the best.

1 Introduction

The desert steppe in Inner Mongolia was located in the northern sand prevention belt of the national ecological security pattern of "two screens and three belts". It was the key construction area of the belt and road initiative area and also was an important natural ecological barrier in China. The desert steppe was characterized by drought climate, strong wind, low rainfall, serious vegetation degradation and it was extremely fragile ecosystem. With the increasing of the scale and intensity of mineral resources construction in desert steppe, the area of loose accumulation abandoned land formed by mining construction and production was increasing continuously. Due to the poor site conditions of the abandoned land, vegetation was lack of effective supply of nutrients and water, and it was difficult to restore vegetation[1,2]. The ecological and environmental problems in desert steppe mining areas were becoming more and more serious, especially in nonferrous metal mine, and had adverse effects on the green mine construction.

Scholars had carried out a large number of researches on the restoration of vegetation in mines around the world. The research results mainly included the influence of the conditions of mining opposite sites, the ecology and comprehensive treatment of abandoned lands, the physical restoration, biological reclamation, phytoremediation technology, erosion resistance and reclamation technology, etc. The United States, Canada, Australia, France and other developed countries had basically realized the comprehensive restoration of land, environment and ecology. The United States mainly focused on the restoration of water bodies and woodlands, Australia focused on mine management and restoration, and France and other European countries focused on the restoration of abandoned land[3-7]. At present, there was a lack of scientific and effective technical means and governance model for ecological restoration in metal mine of desert steppe in China, and the scientific and technological foundation was very weak. In this study, the mine dump in nonferrous metal mine of desert steppe was selected as the research object. According to the artificial remodeling landform characteristics and soil and water loss characteristics of the abandoned land, the vegetation restoration test was carried out. The ecological adaptability and the effect of water storage and soil conservation of different vegetation restoration measures were analysed from the aspects of soil moisture conservation, wind erosion resistance and vegetation restoration. The grey relational degree method was used to quantitatively optimize the comparison and selection. The results would provide a scientific basis for vegetation restoration in abandoned land of nonferrous metal mine.

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2 Materials and methods

2.1 Study area

The study area was located at the nonferrous metal mine dump of Sunite Jinxi Gold Mining Co. Ltd in Xilinguole League, Inner Mongolia. The nonferrous metal mine dump was located in the south of the mining area and covered an area of 40 hm2. It was a stepped landform with platforms and slopes distributed and the relative height is 100m. The height of each step is about 20m. The metal slag was mixed with soil and then discharged to the dump and then covered with soil 50 cm ~ 80 cm. The soil quality was poor and the nutrient content was low according to the test of soil physical and chemical properties. The test area was located in the middle of the Inner Mongolia Plateau and it belonged to the arid and semi-arid climate in the mid-temperate zone. The average annual rainfall is 209 mm, which is concentrated in June to September. The native soil in the test area was sandy soil, and the original vegetation belongs to desert steppe vegetation.

2.2 Experimental design

Vegetation restoration measures adopted in mine dump treatment mainly had three forms, which are shrubs(I), shrub-grass (II), grass (III), and natural restoration plant community without taking measures. The experiment sample plots were set in each vegetation restoration measure, and the windproof soil consolidation and vegetation growth status of each experiment sample plots were analysed, and the effects of soil and water conservation were evaluated.

Table1. Main situation of vegetation restoration measures sample plots.

No.	Measure	Place	The main technical points
I	shrubs	Dump platform	Planting *Caragana korshinskii*, plant row spacing was 2.0m×2.0m.
II	shrub-grass	Dump platform	Planting *Caragana korshinskii*, plant row spacing was 2.0m×2.0m and Sow *Melilotus officinalis*, *Artemisia sphaerocephala* and *Avena sativa* in open space
III	grass	Dump platform	Sow *Melilotus officinalis*, *Artemisia sphaerocephala* and *Avena sativa* in open space
CK	natural restoration	Dump platform	Natural recovery state

2.3 Determination method

Surface soil (0-20cm) was randomly selected from each vegetation restoration sample plot to measure soil water content, Soil moisture content was determined by weighing method. Soil moisture content were tested once a month during the growing season from 2019 to 2020 (June to September). Soil samples were collected in the beginning of September 2020, and soil organic matter content was determined by potassium dichromate volumetric method[8]. The total coverage of vegetation was measured by a self-made 1m2 aluminium alloy frame in the peak growth period of 2020, which was divided into 100 small grids with an area of 1cm2 on average. The aboveground biomass of the vegetation was measured by cutting method. All plants were cut on the ground in 1m2 quadrat and weighed after drying at 80℃. Each measurement index was repeated for 9 times in each sample plot.

Soil wind erosion was measured by chain pin method, and soil wind erosion monitoring areas were set up in each sample. Nine chain pins were buried in the monitoring area, and three rows were laid in the vertical main wind direction, three branches in each row, with an interval of 1m×1m. The height changed between the chain pins and the ground were monitored regularly, and the wind erosion amount was analyzed. The test was conducted every three months from late October 2018 to late November 2020.

2.4 Data analysis

Analytic Hierarchy Process and Grey correlation method were used to determine the comprehensive benefit evaluation index system of vegetation restoration measures, and benefit evaluation and adaptability evaluation were conducted. Analytic hierarchy process can be carried out in the following four steps: (1) establish the hierarchical structure model; (2) construct all judgment matrices in each level; (3) hierarchical single sorting and consistency test; (4) hierarchical total sorting and consistency test[9]. Grey correlation method is a quantitative comparative analysis method. It analyses the correlation degree among the main factors in the system and determines the factor with the largest correlation degree according to the comparability and nearness of the sequence[10]. The basic principle of grey relational degree method is to judge whether the connection is close according to the similarity degree of geometric shapes of sequence curves. If a group of geometric curves are more similar in shape, the greater the correlation. According to this principle, we can find out the primary and secondary factors in the complex system, which can provide information reference for the comprehensive decision making of the system and the improvement of comprehensive benefit.

3 Results and analysis

3.1 Change of vegetation

The plant community of the nonferrous metal mine dump had certain difference after implementing different vegetation restoration measures. the vegetation coverage of the natural restoration plot was only 12%, and a large area of the ground was exposed according to Table 2. After densely planting shrubs in the nonferrous metal mine dump, the survival rate and preservation rate of shrubs were higher, the vegetation coverage reached 47%, and the aboveground biomass was 101 g/m^2. The shrub preservation rate of shrub-grass plots reached 90.2%, the vegetation coverage was 67%, and the above-ground biomass was 132 g/m^2, the plant growth was relatively good. The vegetation coverage of the grass plot was 54% and the aboveground biomass was 84 g/m^2.

Table2. Change of vegetation under different vegetation restoration measures.

Vegetation	I	II	III	CK
vegetation coverage（%）	47	77	54	12
vegetation height（m）	13	17	16	6
above-ground biomass（g/m^2）	84	132	101	18
Shrub retention rate（%）	79.5	90.2		
Shrub survival rate（%）	85.2	96		

3.2 Change of soil properties

Different vegetation restoration measures had a certain influence on the surface soil moisture as shown in the fig. 1, and the surface soil moisture of the natural restoration plots was lower than that of the plots after the implementation of vegetation restoration measures. The average variation of soil water content in each test plot was as follows: shrub-grass (II) > shrubs (I) > grass (III) > natural restoration (CK). The difference of soil water content between three vegetation restoration measures plots and the natural restoration plot was significant ($p<0.05$). The soil water content of shrub-grass plot was the highest, which was 12.5% higher than that of grass plot, and the difference of soil water content between the shrub-grass plot and grass plot was significant ($p<0.05$).

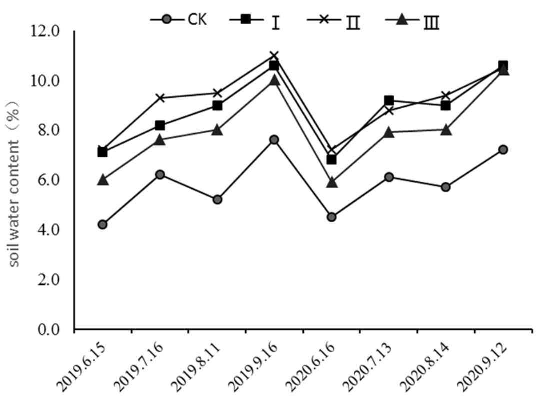

Figure 1. Change of soil water content on different measures.

According to the change of soil organic matter content (Fig. 2), the soil organic matter content of the natural restoration plot was the lowest (4.8 g/kg), and the soil organic matter content of the shrub-grass plot was the highest (5.8 g/kg), which was 17%, 12% and 9% higher than that of the natural restoration plot, shrubs plot and grass plot respectively. The results showed that the vegetation restoration measures had a certain promotion effect on the accumulation of soil organic matter in nonferrous metal mine dump, and provided the basic conditions for the restoration and reconstruction of vegetation. However, the soil organic matter content did not increase significantly after the implementation of vegetation restoration measures, and the soil conditions in nonferrous metal mine dump were poor through comparative analysis. The plant community of the nonferrous metal mine dump had certain difference after implementing different vegetation restoration measures.

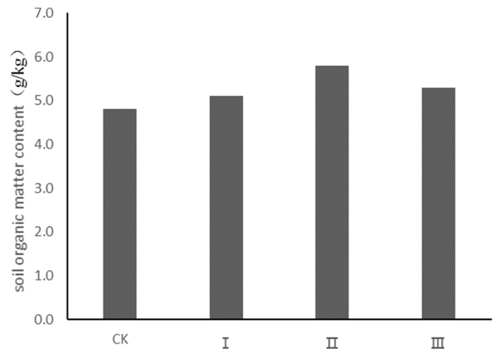

Figure 2. Change of soil organic matter content

3.3 Change of Soil wind erosion

Soil wind erosion resistance of different vegetation restoration measures varied to some extent, and the annual average soil wind erosion thickness changed greatly among different plots. four plots are arranged was as follows according to the annual wind erosion amount: natural restoration (CK) > shrubs (I) > grass (III) >.shrub-grass (II) by the observation results of soil wind erosion (Table 3). Variance analysis showed that the annual wind erosion of natural restoration plot (CK) was significantly different from that of shrubs plot (I), grass plot (III) and shrub-grass plot (II) ($p<0.05$). Wind erosion resistance abilities of different vegetation restoration measures were also different, the soil wind erosion of shrub-grass plot (II) was 53% and 30% lower than that of shrubs plot (I) and grass plot (III) respectively, which indicated that the windproof and soil consolidation ability of shrub-grass measures was better than other vegetation restoration measures.

Table3. Wind erosion index observation on different vegetation restoration measures.

Wind erosion index	I	II	III	CK
average annual wind erosion thickness（mm）	0.6	0.4	0.5	1.9
wind erosion amount（t/hm^2）	8.7	5.7	7.4	30.8

3.4 Change of Soil wind erosion

3.4.1 Comprehensive benefit calculation

The comprehensive benefit evaluation of vegetation restoration measures in the mine dump of nonferrous metal mine could reflected whether the technical measures were suitable for the ecological restoration requirements of local mining areas, so as to achieve the purpose of priority to the application of appropriate technical measures. Evaluation system of weights and calculation model were established by application of analytic hierarchy process (AHP), the evaluation index included soil and water conservation benefit index (soil wind erosion, soil water content, soil organic matter content), ecological index (vegetation coverage, aboveground biomass) and economic benefit index (investment cost and maintenance cost) which were three class a total of seven indicators. Benefit index values of different vegetation restoration measures were determined by actual measured data. The membership function of ascending half trapezoidal distribution and descending half trapezoidal membership function were used to standardize the values of different measures respectively. The standardized values were shown in Table 4. Grey correlation method was adopted to evaluate the comprehensive benefit, the correlation of sequence and measured values were calculated, the evaluation standard size, measured sequences with the reference sequence proximity to assess the testing sequence, and different measures the correlation coefficient of each index was obtained by calculation, and determine the comprehensive benefit correlation (table 5).

Table4. Standardized evaluation index values.

Evaluation index	Ⅰ	Ⅱ	Ⅲ	CK
soil wind erosion	0.71	0.82	0.69	0.31
soil water content	0.43	0.52	0.45	0.18
soil organic matter content	0.24	0.27	0.24	0.13
vegetation coverage	0.63	0.95	0.68	0.21
aboveground biomass	0.69	0.76	0.62	0.4
investment cost	0.36	0.30	0.50	0.95
maintenance cost	0.25	0.32	0.85	0.98

Table5. Comprehensive correlation degree of different measures.

Evaluation index	Ⅰ	Ⅱ	Ⅲ	CK
soil and water conservation benefit index	0.62	0.72	0.61	0.26
ecological benefit iindex	0.63	0.82	0.64	0.35
economic benefit index	0.52	0.49	0.58	0.99
comprehensive benefit index	0.6	0.68	0.61	0.53
Comprehensive benefit ranking	3	1	2	4

3.4.2 Adaptive analysis

Based on the comprehensive benefit analysis, although the economic benefit of natural restoration was high and the ecological management cost can be saved, the water and soil conservation ability of natural restoration vegetation was very low. The vegetation restoration cycle was longer and it was easy to cause serious soil and water loss in the process of ecological restoration. comprehensive benefit of shrubs, grass and shrub-grass vegetation restoration measures all achieved high value, and the differences between each other was lesser, the biggest comprehensive benefit of shrub-grass measures were up to 0.68, the smallest shrubs measure was 0.60, the result showed that three measures were applicable to vegetation restoration in the nonferrous metal mine dump, and had more apparent effect of ecological restoration. Among the three measures, soil and water conservation benefit and ecological benefit of shrub-grass measures was the best, and the economic benefit was slightly lower than the other two measures, the shrub-grass measure should be adopted first in the vegetation restoration of the nonferrous metal mine dump if the economic conditions allow.

4 Conclusion

4.1 Vegetation restoration measures have influence on the soil moisture content and organic matter content in the nonferrous metal mine dump of desert steppe, which enhanced the soil water holding capacity and provided basic conditions for vegetation restoration. However, the soil conditions in mine dump were not conducive to the growth of plants.

4.2 The comprehensive benefit of shrub-grass measures was the highest, up to 0.68, and the soil and water conservation and ecological benefits were obvious through the grey relational degree method. Therefore, it was suitable to be applied in the vegetation restoration and reconstruction of the nonferrous metal mine dump with poor natural conditions and difficult vegetation restoration.

4.3 Due to different natural environmental conditions in different areas, vegetation restoration inevitably presented certain differences. Therefore, vegetation restoration measures need to be modified according to the objective reality, and the specific configuration mode should be determined according to the plant ecological characteristics and local natural conditions.

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References

1. Wei Z Y, Bai, Z K. The Concept and Measures of Runoff-dispersing on Water Erosion Control in the Large Dump of Opencast Mine [J]. Journal of China Coal Society, 2003, 28(5):486-490.
2. Lv G, Liu Y Z, L Y X et al. Evaluation of Soil Hydrology Effects of the Vegetation Restortion in Haizhou Open-pit Coal Mine Dump [J]. Ecology and Environment Sciences, 2017, 26(1):67-72
3. Carter C T , Ungar I A. Aboveground Vegetation, Seed Bank and Soil Analysis of a 31-Year-Old Forest Restoration on Coal Mine Spoil in Southeastern Ohio[J]. American Midland Naturalist, 2002, 147:44-59.

4. Stewart K M E, Penlidis A. Designing polymeric sensing materials for analyte detection and related mechanisms[J]. Macromolecular Symposia, 2016, 36(1): 123-132.
5. Nussbaumer Y, Cole M A, Offler C E, et al. Identifying and ameliorating nutrient limitations to reconstructing a forest ecosystem on mined land[J]. Restoration Ecology, 2016, 24(2): 202-211.
6. Sizmur T, Martin E, Wagner K, et al. Milled cereal straw accelerates earthworm (Lumbricus terrestris) growth more than selected organic amendments[J]. Applied Soil Ecology, 2017, 113- 166.
7. Zhang S L, Mi J X, Hou H P et al. Research Progress on Mining Ecological Restoration: Based on the Report of Three Consecutive World Ecological Restoration Conferences [J]. Acta Ecologica Sinica, 2018, 38(15):345-353.
8. Bao S D. Soil Agrochemical Analysis [M]. Beijing：China Agriculture Press, 2010.
9. Saaty T L. Highlights and critical points in the theory and application of the Analytic Hierarchy Process[J]. European Journal of Operational Research, 2007, 74(3):426-447.
10. Li J , Zhou X , Yan J , et al. Effects of Regenerating Vegetation on Soil Enzyme Activity and Microbial Structure in Reclaimed Soils on a Surface Coal Mine Site [J]. Applied Soil Ecology, 2015, 87:56-62.