Effects of vegetation restoration on ecosystem carbon storage and distribution pattern in semi-arid mining area

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Abstract: In order to explore the effect of artificial planting to promote vegetation restoration on ecosystem carbon storage in coal mining subsidence area, the distribution pattern of ecosystem carbon storage in mining area during vegetation restoration was studied by space-time substitution method.The results showed that : (1) The biomass of vegetation layer increased gradually with vegetation restoration, and the biomass distribution ratio of each component was shrub layer (92.1%) > litter layer (5.5%) > herb layer (2.4%). The biomass of shrub and herb layer was mainly distributed in the aboveground part, the former accounted for 73.2 %, and the latter accounted for 83.4 %. (2) The carbon content of the vegetation layer was shrub (45.5%) > herb (43.6%) > litter (38.7%). The total carbon storage was in the early initial of vegetation restoration (1657.1 kg hm-2) < mid-term vegetation restoration (4830.6 kg hm-2) < mature stage of vegetation restoration (8446.4 kg hm-2), and shrub was still the main storage part of carbon storage in this layer. In summary, vegetation restoration can significantly increase the carbon storage of the ecosystem, the proportion of carbon storage in the vegetation layer gradually increases.

1 Introduction

Since the industrial revolution, human activities have resulted in the release of large amounts of carbon into the atmosphere and a significant increase in atmospheric CO^2 concentrations[1]. Terrestrial ecosystems are one of the Earth's most important carbon sinks. Enhancing the carbon sink capacity of terrestrial ecosystems can effectively absorb and remove excess CO^2 from the atmosphere and mitigate the greenhouse effect[2] Degradation or restoration of vegetation in terrestrial ecosystems is often accompanied by carbon emissions and carbon sinks[3]. It is estimated that China's terrestrial ecosystems sequestered an average of about 1.1 billion tons of carbon per year between 2010 and 2016, reaching about 45% of carbon emissions in the same period, with ecological projects such as the vegetation restoration of degraded land and the return of farmland to forest and grass contributing the vast majority of ecosystem carbon sinksK. An accurate and valid assessment of carbon stocks as a key measure of the carbon sink function of a carbon pool is of great value to regional carbon cycle and source/sink studies.

The Shendong mining area, located in the southern part of the Ordos Plateau, is a typical ecologically fragile zone. Wind erosion is strong and hydraulic erosion is frequent in the area, especially coal mining activities over the years have caused intense gravitational erosion, with large areas of land subsidence, accompanied by the development of a large number of ground cracks[4]. The multi-dynamic erosion coupled with arid climatic conditions has led to the degradation of the ecosystem in the Shendong mining area, and soil erosion is very serious. A large amount of carbon in the carbon pool was lost as a terrestrial carbon source.

This paper uses the spatial and temporal substitution method to–analyses the changes of carbon stocks in the shrub layer, herb layer, and litter layer in the ecosystem to elucidate the effects of artificial vegetation restoration on the carbon stocks of the ecosystem in the semi-arid coal mining subsidence area.

2 Materials and methods

2.1 Study location

The study area is located in Shangwan Town, Ijinholuo Banner, Ordos City, Inner Mongolia, which belongs to Shenfu-Dongsheng Mining District, and is a typical ecological degradation area formed by the subsidence of the land after coal mining. The southern part of the region is loess hilly area, and the northern part is wind erosion and sanding area of Mao Wu Su. The climate is continental arid and semi-arid, with the characteristics of rain and heat in the same period, rainfall is mostly concentrated in summer and autumn, with an average annual precipitation

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of 396 mm and an average annual evaporation of 1790 mm. It is windy and dry in spring and winter, with an average annual wind speed of 3.5 m/s and an average annual temperature of 8.9℃. The soil type in the study area is mainly wind-sandy, with poor soil structure and low organic matter content, and poor water and fertilizer retention. The main plant cover types are shrubs, semi-shrubs and perennial herbs, and common species include Artemisia ordosica, Salix cheilophila, *Hippophae rhamnoides*, Setaria viridis, Stipa bungeana, etc.

2.2 Measurement of indicators

The basic growth parameters (plant height, crown width, basal diameter, etc.) were recorded in each shrub sample plot by plant species, and three standard plants were selected accordingly, and the fresh weight of above-ground and below-ground parts of the standard plants were obtained by the full digging method and sampled proportionally. Herbaceous samples were obtained by mowing method to measure the fresh weight of above and below ground parts and sampled. All litter was harvested, fresh weight was determined, and samples were taken. Plant sample were heat at105℃ for 2 hours to sterilizing enzyme,and then dried to constant weight at 85 ℃.50 g of the treated samples were taken separately and the plant organic carbon content was determined by the external heating method using potassium dichromate-concentrated sulfuric acid oxidation.

2.3 Data analyses

Calculation of carbon stock in vegetation layer:

$$C = Ws\times CFs+ Wh\times CFh+ Wl\times CFl$$

where C is the carbon stock of vegetation layer(kg hm-2), Ws is the shrub layer biomass (g m-2), CFs is the shrub layer carbon rate (g kg-1), Wh is the herb layer biomass (g m-2), CFh is the herb layer carbon rate (g kg-1), Wl is the litter biomass (g m-2), and CFl is the litter carbon rate (g kg-1).

Experimental data processing and statistical analysis were performed using Excel and SPSS 20.0 software. Sigmaplot 14.0 software was used for in-text inset mapping. The Least Significant Difference (LSD) method was selected to test the significance of differences (α=0.05) in the spatial and temporal distribution of carbon stocks in the mining ecosystems at different vegetation restoration stages.

3 Results

3.1 Biomass characteristics of different vegetation restoration stages

Table 1 Biomass allocation characteristics of plants layer during vegetation restoration

Sample site Type	Shrubs			Herbaceous		Litter /(g m^{-2})	Total biomass /(g m^{-2})
	Plant species	Aboveground vegetation /(g m^{-2})	Underground vegetation /(g m^{-2})	Aboveground vegetation /(g m-2)	Underground vegetation /(g m-2)		
Initial vegetation restoration	*A. ordosica*	158.3±23.6c	45.8±8.9c	42.5±11.3a	8.3±2.6a	28.4±7.5b	366.2±46.2c
	H. mongolicum	52.6±8.9d	30.3±5.5c				
Mid-term vegetation restoration	*S. psammophila*	566.7±54.1b	278.6±74.1b	19.3±8.2b	4.1±1.3b	60.7±14.9a	1014.3±274.1b
	A. ordosica	58.6±8.2d	26.3±4.2c				
Mature vegetation restoration	*H. rhamnoides*	1233.4±225.4a	369.7±54.9a	2.8±0.7c	0.5±0.2c	77.2±22.1a	1745.5±355.8a
	A. ordosica	40.1±6.7d	21.8±3.7c				

As shown in Table 1, the vegetation biomass differed significantly (P<0.05) at different restoration stages and showed a trend of gradual increase with vegetation restoration. The total biomass showed that initial vegetation restoration (366.2 g m-2) < mid-term vegetation restoration (1014.3 g m-2) < mature vegetation restoration (1745.5 g m-2). The shrub layer is the main part of the vegetation layer biomass, with an average proportion of up to 92.1%, and the proportion will gradually increase with the recovery of vegetation. The percentage of biomass in the litter layer was relatively small, averaging 5.5%, and likewise tended to increase with the proportion of vegetation restoration. The herbaceous layer accounted for the smallest proportion, accounting for only 2.4% of the biomass of the entire vegetation layer, and the proportion gradually decreased as the depression of shrubs increased. In terms of the spatial distribution of biomass, the shrub layer biomass was mainly concentrated in the aboveground part, accounting for an average of up to 73.2%, while the Underground part was relatively small, accounting for only 26.8%. The herbaceous layer biomass was likewise mainly concentrated in the aboveground part, with an average of 83.4%, and the Underground part allocated only 16.6% of the biomass.

3.2 Carbon stock characteristics of vegetation layers in different vegetation restoration stages

The overall carbon content of the vegetation layer showed shrubs (45.5%) > herbs (43.6%) > litter (38.7%). The spatial distribution of plant carbon content showed that shrubs were aboveground (48.6%) > underground (42.9%), while herbs were underground (44.9%) > aboveground (42.3%). In terms of variability of carbon content of plant species, S. psammophila (47.8%) > H. rhamnoides (46.4%) > A. ordosica (45.4%) > H. mongolicum (44.2%). From the different stages of vegetation restoration, the average carbon content of the vegetation layer in the middle stage of vegetation restoration was the highest (44.9%), followed by the mature stage of vegetation restoration (44.0%) and the lowest in the early stage of vegetation restoration (43.5%).

As shown in Table 2, there were significant differences ($P<0.05$) in the carbon stocks of the vegetation layer at different restoration stages, and there was a tendency to increase with the restoration of vegetation. The total carbon stock showed that the initial vegetation restoration (1657.1 kg hm-2) < mid-term vegetation restoration (4830.6 kg hm-2) < mature vegetation restoration (8446.4 kg hm-2). The shrub layer is the main storage part of carbon storage in the vegetation layer, with an average proportion of 93.4%, and the proportion of shrub carbon storage is increasing in the process of vegetation restoration. Litter layer is a smaller carbon reservoir, with an average of 4.3% of carbon storage, and the proportion will also increase with vegetation restoration. The herbaceous layer has the weakest carbon storage capacity due to the small stock and insufficient biomass accumulation, accounting for only 2.3% of the carbon stock of the whole vegetation layer. Moreover, as the mature forest of shrubs has encroached on most of the ecological niches, the herbaceous plants have gradually disappeared in the mature stage of vegetation recovery, and the carbon stock is very small. From the spatial distribution of carbon storage, the carbon storage in the shrub layer is dominated by the aboveground part, accounting for up to 76.1%, while the underground part only accounts for 23.9%. The carbon storage in the herbaceous layer is also dominated by the aboveground part, accounting for 82.6% on average, and the underground part accounts for less carbon storage, accounting for only 17.4%.

Table 2 Carbon storage allocation characteristics of plants layer during vegetation restoration

Sample site Type	Shrubs			Herbaceous		Litter /(kg hm-2)	Total carbon stock /(kg hm-2)
	Plant species	Aboveground vegetation /(kg hm-2)	Underground vegetation /(kg hm-2)	Aboveground vegetation /(kg hm-2)	Underground vegetation /(kg hm-2)		
Initial vegetation restoration	A. ordosica	763.0±125.3c	194.7±33.6c	183.2±23.6a	36.7±5.4a	108.5±16.7c	1657.1±223.9c
	H. mongolicum	243.5±36.5d	127.6±21.1cd				
Mid-term vegetation restoration	S. psammophila	2805.2±311.5b	1284.3±253.9b	82.0±16.3b	18.4±2.6b	246.4±37.2b	4830.6±583.4b
	A. ordosica	282.5±47.6d	111.8±14.7d				
Mature vegetation restoration	H. rhamnoides	6327.3±884.1a	1530.6±213.1a	11.6±1.7c	2.3±0.4c	288.7±25.8a	8446.4±672.8a
	A. ordosica	193.3±22.5d	92.7±12.8d				

4 Conclusion

The semi-arid mining area has formed a large area of hollow areas due to coal mining, and the massive appearance of land subsidence and ground cracks, under the combined effect of wind and water erosion, has resulted in serious damage to soil structure, reduced stability of plant communities, and loss of ecosystem carbon pool[5]. Artificially established vegetation restoration measures are an effective means to curb this degradation trend and help to re-establish a good vegetation system in the coal mining subsidence treatment area, reverse land degradation, and protect and increase the ecosystem carbon pool[6]. In this study, the vegetation layer and soil layer are two important components of the carbon pool of the mining ecosystem. In the process of vegetation restoration, the remodeling of microhabitats directly changed the carbon storage capacity of the components, increased the carbon storage of the vegetation-soil system, and formed a distinct spatial and temporal distribution pattern of carbon storage.

In arid and semi-arid regions, where moisture conditions are the main limiting factor for ecosystems, shrubs often become the mainstay of regional ecological restoration and vegetation construction because of their strong adaptability to drought and barrenness[7]. Because of their rapid growth and large root systems, they form an effective plant protection system after a few years of establishment, effectively controlling ground erosion and soil, and constantly changing the soil microcosm[8] The results of the study showed that the shrub layer was the main embodiment of the biomass and carbon storage of the vegetation layer in the mining area, and more than 92% of the vegetation dry matter accumulation and carbon storage were contributed by shrubs. This is consistent with the findings of Wang B et al[9]on carbon stock allocation in desert ecosystems during the reversal of desertification. A study by Sandan et al[10] on the restoration of vegetation in semi-arid grassland mining areas also showed the dominance of shrubs in similar habitats. These results fully demonstrate that the ecological restoration of mining sites with difficult site characteristics should prefer the configuration of native shrubs with excellent traits. It can not only promote positive community succession and maintain stability, but also significantly increase the ecosystem carbon stock and form a good biomass carbon sink. The data analysis showed that 76.1% of carbon storage in the shrub layer was allocated to the aboveground stem and leaf fraction, and the underground root system accounted for a relatively small proportion. This distribution pattern reflects the adaptability of plants to adversity and survival strategies. With low precipitation and shortage of water resources in the Shendong mining area, H. rhamnoides and others can only use a small amount of water infiltrated from the shallow soil after rainfall, which restricts the growth of deep-rooted types, and most of the resources are used for aboveground branch and leaf growth, and root growth is restricted and the carbon storage capacity is relatively weak[11]. It is noteworthy that the cover, biomass and carbon stock of herbaceous plants showed a significant decreasing trend with the shrub establishment process. This may be due to the presence of chemosensory effects of shrubs such as H. rhamnoides and A. ordosica. Compounds such as alkaloids inhibit the seed germination and seedling growth of herbs through root secretion or rain shower, weakening the share of herbaceous layer in the vegetation layer[12-13].

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