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Effects of Different Vegetation Restoration Patterns on Soil Biological Characteristics in Mining Subsidence Area —A Case Study of Jiaozuo Forest Park

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Abstract

Land reclamation and ecological reconstruction in mining subsidence area are important measures to improve the ecological environment of mining areas. Soil is the key factor to mainten the functional stability of restored ecosystem, different reclamation and utilization patterns have different effects on soil characteristics. The reclaimed soil microbial characteristics of artificial lawn, red maple forest, acacia forest, and flower bed in forest park of Jiaozuo city are studied through the field investigation and laboratory analysis. The results show that, compared with the artificial lawn, the other three vegetation restoration patterns significantly improve the soil microbial characteristics of the reclaimed soil. The effects of four vegetation restoration patterns on soil nutrients and soil biological characteristics are artificial lawn<red maple forest< acacia forest < flower bed. Relevant analysis shows that, the biological characteristics of the reclaimed soil are closely related to soil nutrients. Especially soil organic carbon is significantly positively correlated with each of the soil microbial properties ($P<0.01$), such as SMBC, SMBN, SMBC/ SMBN, qMB, soil enzyme activity and soil respiration rate.

Keywords: mining subsidence, land reclamation, reclamation mode, soil microbial characteristics

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INTRODUCTION

Coal mining has made important contributions to China's economic development, but it has also caused serious damage to land resources in the course of coal resource development, In particular, mining subsidence leads to uneven surface and widespread cracks (gaps). So that the cultivated land can't be irrigated and cultivated, which seriously affects the productivity of cultivated land, the farmers lose confidence in agricultural production, and a large number of good farmland is wasted (Ma et al. 2014). Due to the high cost of management and the lack of fillable soil sources, most of the sunken farmland has not been effectively controlled, which results into a large number of abandoned mining areas and many ecological and social problems in the subsidence area. If the subsidence area can be managed scientifically according to the local conditions, which not only save the cost of management, but also have important practical significance and theoretical value for land reclamation and ecological reconstruction in the mining area.

Soil is an important part of the ecosystem. The restoration of soil ecological function is the key to land reclamation and ecological reconstruction, and the ecological function of soil depends on the properties of soil. Soil organisms, especially microorganisms plays an important role in maintaining soil biological activity, promoting the cycle of C and N elements in soil and mineral decomposition, maintaining soil fertility and plant growth and development, etc. (Fan et al. 2011). In recent years, some scholars have carried out many studies of land reclamation and ecological reconstruction on damaged land in different types of mining areas (Bai et al. 2006, Fan et al. 2003, Huang and Luo 2003). In view of the microbiological characteristics of reclaimed soil, Fang et al. (2007) studied the relationship between soil microorganism and soil properties of reclaimed soil in the drainage field with antaibao open-pit mine as the research object. Fan et al.

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(2011) studied the effects of different reclamation years and vegetation patterns on the microbial population of reclaimed soil. These studies have studied the changes of soil microbial biomass from the aspects of the reclamation period, the reclamation method and the reclamation vegetation model. However, these researches mainly focus on land reclamation and ecological reconstruction in open mining areas. Because of direct excavation and accumulation of waste soil and rocks, open mining has caused devastating damage to the original ecological system, which has eliminated the original landform, vegetation, and soil structure. Hence, the structure and function of the reclaimed soil are quite different from that of the original ecosystem. Although mining subsidence has also caused damage to the land, the initial soil conditions to maintain the soil function are still in place. However, at present, the research on the management of mining area subsidence land mainly focuses on engineering recovery technology, reclamation method, water and fertilizer loss prevention and soil characteristics improvement (Bai et al. 2006, Chen et al. 1999, Ma et al. 2014). However, there are few comparative studies on the effects of different vegetation reclamation and utilization modes. Li et al. (Chen et al. 1999) studied the soil nutrients of the reclaimed soil in the subsidence area under different reclamation methods, such as yellow drainage filling, coal gangue filling and pre-reclamation. However, the ecological effects after treatment have not been studied from the aspects of how to improve soil properties. Land reclamation and ecological reconstruction in coal mining subsidence areas should not only restore and rebuild vegetation on the ground, but also pay attention to the restoration of soil ecological functions (Fan et al. 2011). Soil microorganisms, as living organisms in the soil, are sensitive to environmental changes and can respond quickly to changes in soil environmental quality and health status. It is an important biological index of soil environmental quality and ecosystem function evaluation (Harris 2003, Schloter et al. 2003). Thereby, the study on soil microbiology characteristics and related influencing factors under different reclamation modes can provide a reliable scientific basis for the evaluation of soil quality.

Jiaozuo forest park is located in the former coal mining subsidence area of zhucun mine. The topography of the subsidence area fluctuates greatly, which is not conducive to agricultural production. With the improvement of people's awareness of ecological environment, according to local conditions, the local government has carried out garden-style greening of the subsidence area and achieved remarkable results. It has become the largest urban forest with the most complete ecological function. However, human activities on land exploitation and utilization will inevitably affect soil habitat conditions, which will have different degree effects on soil microbiology characteristics in different directions (Xie et al. 2004). Therefore, taking Jiaozuo forest park in henan province as the research object, this study is conducted to analyze the characteristics soil nutrients and soil microbiology under four typical vegetation restoration modes, explore the effects of different vegetation restoration modes on reclamation, so as to provide scientific basis for improving the fertility condition of reclaimed soil and optimizing the ecological environment of the study area.

OVERVIEW OF RESEARCH AREA AND RESEARCH METHODS

Overview of Research Area

Jiaozuo city forest park is located in the west jiaozuo central station district (113°38′E, 35°29′E). It is a warm temperate continental monsoon climate. The annual average temperature was 12.8°C-14.8°C, annual rainfall was 538.2-586.9 mm. The park covers an area of over 150hm^2. The park was originally a coal mining collapse area of Zhucun mine of Jiaozuo coal group. The mine was put into production in 1958, and long-term coal mining resulted in a large area of land subsidence in the mining area. Although the topography of the subsidence area fluctuates greatly, which is not conducive to agricultural production, its surface soil and climate conditions are conducive to vegetation restoration. According to local conditions, it was built into the forest park by the municipal government in 1995. At present, the main tree species in the park are poplars, acacia trees, willows, paulownia trees, cedar trees, luan trees, large leaf privet trees, ginkgo, torchbearer trees, red maple, etc.

Sample Site Setup and Sample Collection

This experiment was conducted in March 2017. The characteristics of soil microbiology of 4 kinds of typical vegetation restoration models: the lawn(CK), red maple's woods (S1), black locust forest (S2), and flower beds (rose) (S3). The lawn is greatly disturbed by human activities, the red maple forest and robinia pseudoacacia forest are relatively less disturbed by human, and the flower bed has been maintained and managed by gardeners for a long time. Soil samples within the 0-30 cm layer were collected in each sampling plot using a 5-point random sampling method. The soil samples were sealed in bags, brought to the laboratory and stored in a refrigerator at a temperature of 4°C prior to measurement.

Measuring Items and Methods

For each soil sample the following data was obtained: soil total nitrogen (STN), measured using the Kjeldahl method; soil organic carbon (SOC), measured using the potassium dichromate method; soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN), measured using the fumigation extraction method (Vance et al. 1987); urease activity, measured by colorimetry; and sucrase activity, determined by 3, 5-dinitrosalicylic acid colorimetry (Yao and Huang 2006). Soil respiration rate was measured with EGM-4 portable soil respirator (PP Systems, Amesbury, MA, USA) at each sampling point. Samples at each sampling point were collected three times. The weeds and litter on the soil surface were cleared before measurement.

Statistical Analysis

Statistical analyses were performed using Excel 2003 and SPSS 13.0. Statistically significant differences were identified using analysis of variance (ANOVA) and least significant difference (LSD) tests at the 0.05 and 0.01 levels, respectively.

RESULTS AND DISCUSSION

Soil Nutrient Characteristics under Different Vegetation Reclamation Modes

Soil nutrient characteristics can not only reflect the nutrient storage level in the soil “nutrient bank”, but also reflect the availability of soil available nutrients (Erwin et al. 2013). Mining subsidence damages soil structure, which easily causes soil water and fertilizer loss and deteriorates soil quality. Land reclamation in the subsidence area can not only reduce the loss of water and fertilizer, but also improve soil quality and soil fertility (Li et al. 2007). This study showed there were significant differences in soil organic carbon, total nitrogen (TN) and total phosphorus (TP) between different vegetation reclamation modes. Due to the larger interference from tourists’ activities, SOC of artificial lawn (CK) is significantly lower than that of other three vegetation reclamation modes (**Table 1**). The content of organic carbon in S1, S2, and S3 increased by 71.46%, 127.96% and 170.63% compared with CK, respectively. The total N content (TN) of S1 was significantly lower than that of CK, and TN of S2 and S3 were significantly higher than that of CK. The total P (TP) content of S1 was significantly lower than that of CK, TP content of S2 was similar to that of CK, and TP of S3 was significantly higher than that of CK.

Table 1. Soil nutrient content under different vegetation restoration patterns

	SOC (g/kg)	TN (g/kg)	TP (g/kg)	C/N
CK	15.70±1.35d	1.16±0.01b	0.66±0.01b	13.52±1.12d
S1	26.92±1.33c	0.90±0.02c	0.59±0.01c	30.34±2.11a
S2	35.79±10.16b	1.58±0.01a	0.64±0.01b	22.64±1.47c
S3	42.49±8.52a	1.60±0.03a	0.73±0.01a	26.64±2.22b

Different letters in the same column indicate that there are significant differences between treatments at $P < 0.05$.

Due to long-term maintenance by park workers, SOC, TN and TP in S3 were significantly higher than that S1 and S2. The content of TN in S2 was significantly higher than CK, mainly because robinia pseudoacacia belongs to the legume family, which can mmobilize nitrogen from the air into the soil, thus significantly increasing TN in soil. The ratio of SOC to TN (C/N) can reflect the satisfaction degree of the basic nutrient environment for microbial activities in soil. The C/N of S1、S2 and S3 was significantly higher than that of CK, and C/N of them increased by 124.41%, 67.46% and 97.04%, respectively, compared with the control.

Changes in Soil Microbial Biomass C, Microbial Biomass N and Microbial Biomass Quotient under Different Vegetation Reclamation Modes

Soil microbial carbon (SMBC) and microbial nitrogen (SMBN) are the reservoirs of soil active nutrients and important sources of plant nutrients (Li et al. 2008). Different vegetation reclamation methods have different effects on the amount of microorganisms in the reclaimed soil (Fan et al. 2007, 2011), thus affecting the content of SMBC and SMBN. This study showed that there were significant differences in SMBC and SMBN contents among four different vegetation reclamation modes. The content of SMBC and SMBN was significantly increased in S1, S2 and S3 sample sites compared with the artificial lawn (CK) with strong interference from tourists. SMBC and SMBN showed a trend of S3 > S2 > S1 > CK (**Fig. 1**). Among them, due to the influence of long-term maintenance by park gardeners, the contents of SMBC and SMBN of S3 increased by 184.03% and 79.71% compared with CK, respectively. SMBC/SMBN can reflect the change information of microbial community composition and structure, and the higher SMBC/SMBN is, the more complex the microbial community is in the soil (Li et al. 2008). This study showed that the SMBC/SMBN of S1, S2 and S3 were significantly increased by 15.82%, 62.77% and 57.24% compared with CK, respectively, indicating that the soil microbial community structure of S1, S2 and S3 was superior to that of CK. The percentage of SMBC in total soil organic carbon (SOC) content is called soil qMB, which can reflect the capacity of soil activated carbon and the characteristics

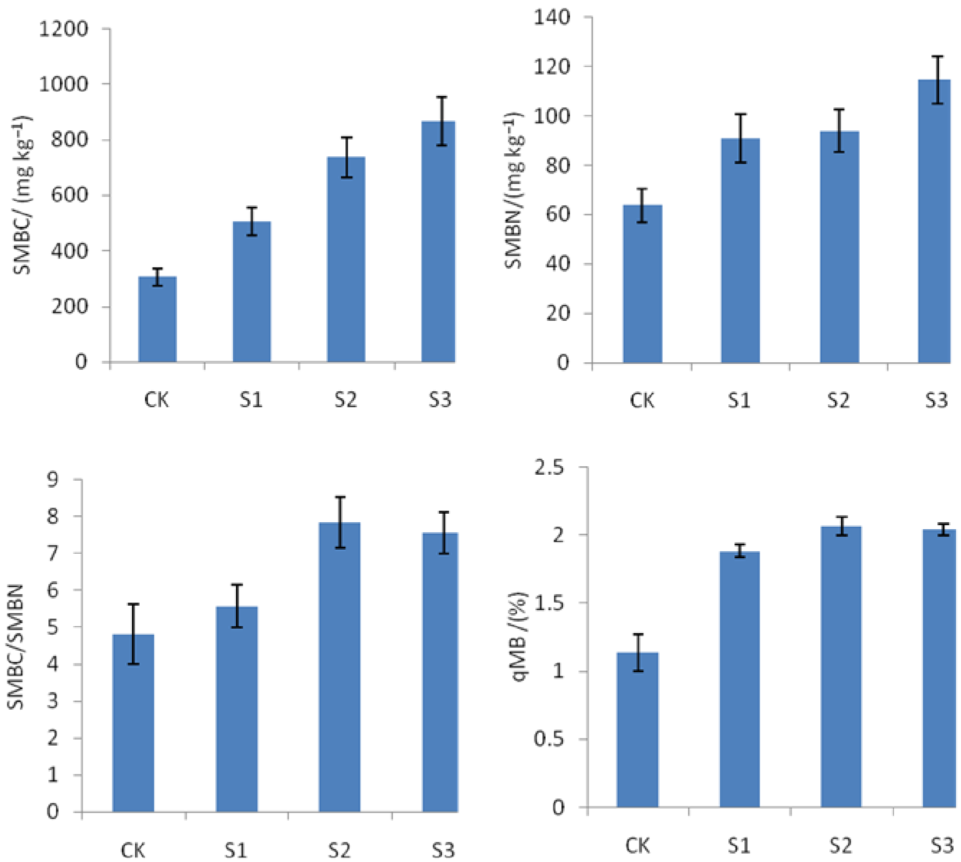

Fig. 1. SMBC, SMBN, SMBC/ SMBN and qMB under different vegetation restoration patterns

of soil activity (Li et al. 2008). The higher qMB is, the higher the proportion of active organic carbon is in the soil. Therefore, qMB can also indicate changes in soil evolution and soil health (Ren and Crego 2000). Previous research showed that the qMB value of soil was generally between 1% and 4% (Brookes et al. 1985). In this study, the range of qMB was 1.13% to 2.04%, and the qMB of S1, S2 and S3 soil was significantly higher than that of the control. The above studies on microbiological characteristics demonstrated that the soil active nutrients, microbial community structure, the degree of soil evolution and soil health in S1, S2 and S3 s were significantly better than those of CK.

Soil Respiration Rate and Soil Enzyme Activity in Different Vegetation Restoration Modes

Soil respiration is mainly composed of three biological processes: soil microbial respiration, plant root respiration and soil invertebrate respiration (Singh and Gupta 1997). Soil enzyme is a biocatalyst formed by the secretion of plant roots and microorganisms in the soil and the decomposition of animal and plant residues (Zhou and Ding 2007). Therefore, soil respiration rate (SRR) and soil enzyme activity, as indicators of soil biological activity, reflect soil biological characteristics, material metabolic intensity and the ability of nutrient transformation and supply in the soil (Nael et al. 2004). There was a significant difference in soil respiration intensity between different reclamation modes. Soil respiration rate of S1, S2 and S3 increased significantly compared with CK (**Fig. 2**). The decomposition and transformation of soil organic matter, nutrient fixation and release, and various REDOX reactions are all carried out with the participation of various soil enzymes. Among various enzymes present in soil, the activities of soil urease and invertase can be used as the indicators reflecting the conversion and supply intensity of nitrogen and carbon in the soil, respectively. They are the important enzymes indicative of the biochemical activities of soil (Zhou and Ding 2007). There were also significant differences in soil Urease and Sucrose activity between different vegetation reclamation modes. The activity of Urease and Sucrose in S1, S2 and S3 was significantly higher than those of CK. It is clear that different land reclamation patterns have different effects on soil biological characteristics, and soil respiration, sucrose enzyme and urease activity all presented the change trend of S3> S2>S1>CK.

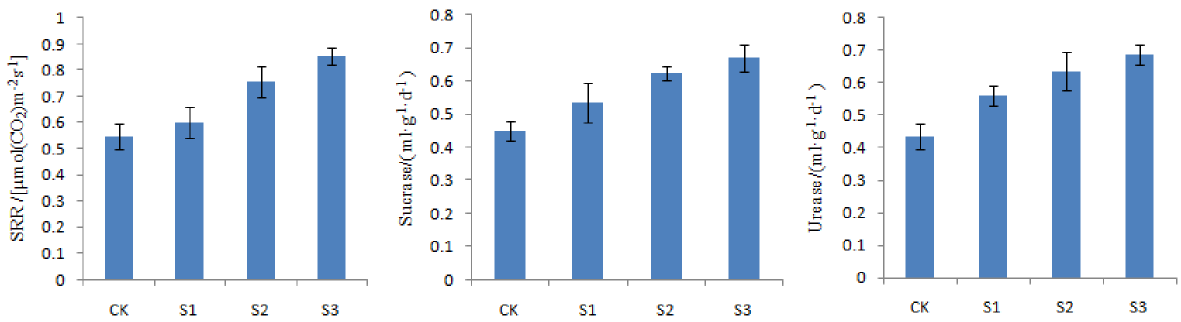

Fig. 2. Soil enzyme activity and SRR under different vegetation restoration patterns

Table 2. Correlative coefficients between soil microbial properties and soil nutrients

Items	SMBC	SMBN	SSR	Sucrose	Urease	qMB	SMBC/SMBN
SOC	.986**	.953**	.937**	.979**	.964**	.841**	.907**
TN	.730**	.528	.822**	.687*	.634*	.387	.787**
TP	.487	.405	.677*	.471	.400	.029	.403
C/N	.536	.720**	.358	.577*	.609*	.759**	.370

* indicates a significant correlation at $P < 0.05$, and ** denotes a significant correlation at $P < 0.01$

Correlation Analysis of Soil Nutrient and Soil Biological Characteristics under Different Vegetation Reclamation Modes

There is a close relationship between soil biological characteristics and soil nutrient (Fan et al. 2011). In particular, soil microbial biomass C (SMBC) and microbial biomass N (SMBN) were positively correlated with soil organic carbon (SOC) and total nitrogen (Erwin et al. 2013). Studies on reclaimed soil also showed that microbial biomass of reclaimed soil is closely related to soil nutrients (Fan et al. 2011). In this research, based on under different vegetation reclamation modes the correlation analysis of soil biological characteristics and soil nutrients (**Table 2**) showed that soil SMBC, SMBN, SMBC/SMBN, soil microbial quotient (qMB), soil enzyme activity and soil respiration rate (SRR) were very significant positive correlation with the SOC ($p < 0.01$); SMBC, SMBC and SMBN and soil respiration rate (SRR) were very significant positive correlation with soil total N ($p < 0.01$), Soil Urease and Sucrose activity were significantly positively correlated with total N ($p<0.05$). In the measured soil biological characteristics, except that soil respiration rate was significantly positively correlated with total P, other biological characteristics were positively correlated with total P, but not significantly. SMBC/ SMBN and qMB were significantly positively correlated with soil C/N ($p<0.01$). There was a significant positive correlation between soil enzyme activity and soil C/N ($p<0.05$). SMBC, SMBC/ SMBN and SRR were positively correlated with soil C/N, but not significantly. Zang et al showed that soil qMB significantly associated with SMBC and SRR, but there was no correlation between soil nutrient (Zang et al. 2015), this study showed that soil qMB had significantly positive correlation with SOC, soil C/N.

CONCLUSION

Different modes of vegetation restoration have different degree of influence on SOC, total N and total P of soil. SOC and C/N in S1,S2 and f S3 sample plot were significantly higher than those of CK. SOC, total N and total P content in S3 sample area were significantly higher than those of CK.

Soil respiration, urease and invertase activity, SMBC, SMBN, SMBC/SMBN and qMB in S1, S2 and S3 were significantly higher than those of CK, which indicates that soil microbial community structure, degree of soil evolution and soil health of the three sample plots were significantly better compared with CK.

Soil microbial characteristics of different vegetation restoration models is closely related to the soil nutrients, the SOC especially notably positive correlated with SMBC, SMBN, SMBC, SMBN, qMB, soil enzyme activities and soil respiration rate.

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