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Effects of different vegetation restoration models on soil microbial biomass in eroded hilly Loess Plateau, China

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Abstract Vegetation restoration is a key measure to improve the eco-environment in Loess Plateau, China. In order to find the effect of soil microbial biomass under different vegetation restoration models in this region, six trial sites located in Zhifanggou watershed were selected in this study. Results showed that soil microbial biomass, microbial respiration and physical and chemical properties increased apparently. After 30 years of vegetation restoration, soil microbial biomass C, N, P (SMBC, SMBN, SMBP) and microbial respiration, increased by 109.01%–144.22%, 34.17%–117.09%, 31.79%–79.94% and 26.78%–87.59% respectively, as compared with the farmland. However, metabolic quotient declined dramatically by 57.45%–77.49%. Effects of different models of vegetation restoration are different on improving the properties of soil. In general, mixed stands of *Pinus tabulaeformis*–*Amorpha fruticosa* and *Robinia pseudoacacia*–*A. fruticosa* had the most remarkable effect, followed by *R. pseudoacacia* and *Caragana korshinkii*, fallow land and *P. tabulaeformis* was the lowest. Restoration of mixed forest had greater effective than pure forest in eroded Hilly Loess Plateau. The significant relationships were observed among SMBC, SMBP, microbial respiration, and physical and chemical properties of soil. It was concluded that microbial biomass can be used as indicators of soil quality.

Keywords eroded hilly Loess Plateau, vegetation restoration, soil microbial biomass, soil quality

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1 Introduction

Vegetation restoration is an important way to improve eco-environment on the Hilly Loess Plateau, a serious soil erosion region and an important region practicing Project of Converting Farmland to Forest and Grassland in China. Vegetation restoration can improve soil properties by soil-vegetation combination system besides conserving soil and water effectively. Soil microorganism is an important parameter and driving force on material cycle and energy flow. Soil microbial biomass C, N, P (SMBC, SMBN, SMBP) is a reservoir pool of active soil nutrition substance. Moreover, it can reflect the change of environmental factor and land use type sensitively because of its short cycle period. Generally, soil microbial biomass was considered as one of important evaluation index on soil properties (Paul and Voroney, 1980; Jenkinson and Ladd, 1981; Powlson et al., 1987; Ross, 1990; Anderson and Dormsch, 1993; Sparling and Ross, 1993). At present, some scholars studied the change of the physical and chemical properties of soil after vegetation restoration, but the microbial biomass of soil in erosion environment has not been reported widely (Wang et al., 2002; Gong et al., 2005; Jiao et al., 2005). The evolvement of soil quality after vegetation restoration was studied in the sight of soil microorganism to seek the action principle of vegetation restoration and rebuilding.

2 Study site

This study was carried out at the Zhifanggou watershed of Ansai Research Station of Soil and Water Conservation, located in the semi-arid region of Loess Plateau (36°46'42"–36°46'28"N, 109°13'46"–109°16'03"E). The study site belongs to typically hilly and gully loess region with an elevation of 1,010–1,400 m, and is dominated by a warm temperate continental monsoon with the typical characteristics of severe spring drought in North China. The annual mean temperature is 8.8°C, and annual precipitation is 505.3 mm. Soil is loess soil. The station was established in 1973 to monitor eco-environment for a long term in fixed position because

this area was destroyed by human activity. The ecosystem in this area has gone through five stages: severe damage stage (1938–1958), sustaining damage stage (1959–1973), instable stage (1974–1983), restoration stage (1983–1990) and benign ecosystem stage (1991–now). The restoration and regeneration of vegetation were adopted to conserve soil and water and restore degenerated ecosystem. The ratio of forest area to the whole watershed area increased dramatically from 5% to 40%, and eco-economic system of the area develops well after 30 years' comprehensive control (Liu, 1999).

In order to find the effects of soil microbial biomass under different vegetation restorations in this region, six long trial sites were studied since the vegetation restoration in 1975. They are *Robinia pseudoacacia* L. (RP), *Caragana korshinkii* Kom. (CA), *Pinus tabulaeformis* Carr. (PT), *P. tabulaeformis*-*Amorpha fruticosa* Linn. (PA), *R. pseudoacacia*-*A. fruticosa* (RA), and fallow land (FL) (Table 1).

3 Sample collection and analysis

Six soil samples from 0 to 20 mm along "S" type in each trial site were gathered, which were mixed together as a representational sample in July, 2005. At the same time, the soil sample of Sloping Cropland (CK) at the same exposure from Panlong Mountain was gathered as control. The soil samples were divided into two parts. One was used to determine soil microbial biomass by chloroform fumigation-extraction method (He, 1994; Horwath and Paul, 1994) and respiration intensity by means of lye assimilation (Xu

and Zheng, 1986). Potassium sulfate was adopted to leach it after chloroform fumigation, and determined SMBC, SMBN and SMBP by Tekmar-Dohrmann Apollo 9000 TOC Combustion Analyzer and anti-colorimetry about molybdenum and antimony. The other was used to determine the pH value, total nitrogen, total phosphorus, organic matter, available phosphorus and available potassium after air drying and sieving (Lu, 1999). Moreover, Laser MS 2000 Granularity Analyzer was adopted to determine soil microaggregate. The analysis of variance (ANOVA) and correlation coefficient were analyzed by SAS 6.12.

4 Results and analysis

4.1 Differentiation characteristics of soil microbial biomass

Soil microbial biomass is the total activated organic matter, the volume of which is smaller than $5 \times 10^3 \mu\text{m}^3$, and it is also an important parameter of soil fertility character and driving force of material cycle and energy flow. Table 2 shows that the microbial biomass increased dramatically in respect of sloping farmland and its amplification is from 109.01% to 144.22% after vegetation restoration. In general, mixed stands of *P. tabulaeformis*-*A. fruticosa* and *R. pseudoacacia*-*A. fruticosa* had the most remarkable effect, followed by *Robinia pseudoacacia* and *C. korshinkii*, while fallow land and *P. tabulaeformis* was the smallest. The amplification scope of SMBN is from 34.17% to 117.09%, followed the order: *C. korshinkii* > *R. pseudoacacia* > *P. tabulaeformis*-*A. fruticosa* > *R. pseudoacacia*-*A. fruticosa*

Table 1 Information of the sample plots

Plot	No.	Landform	Exposure	Slope gradient /°	Altitude /m	Soil type	Herbage type
Sloping farmland	CK	Slope	N	22	1,175	Loess	<i>Setaria italica</i>
Fallow land	FL	Slope	N	20	1,206	Loess	<i>Artemisia sacrorum</i>
<i>Robinia pseudoacacia</i>	RP	Slope	NE10°	32	1,129	Loess	<i>Lespedeza dahurica</i> - <i>Stipa bungeana</i>
<i>Caragana korshinkii</i>	CA	Slope	NW 45°	24	1,029	Loess	<i>Artemisia sacrorum</i> - <i>Stipa bungeana</i>
<i>Pinus tabulaeformis</i>	PT	Slope	N	27	1,166	Loess	<i>Artemisia sacrorum</i> - <i>Carex lanceolata</i>
<i>P. tabulaeformis</i> - <i>A. fruticosa</i>	PA	Slope	N	24	1,142	Loess	<i>Artemisia sacrorum</i> - <i>Stipa bungeana</i>
<i>R. pseudoacacia</i> - <i>A. fruticosa</i>	RA	Slope	N W 56°	27	1,185	Loess	<i>Artemisia sacrorum</i>

Table 2 Microbial biomass, respiration strength and metabolism quotient (qCO₂) values of soil in different vegetation restoration types (n = 3)

Plot	SMBC /(mg·kg ⁻¹)	SMBN /(mg·kg ⁻¹)	SMBP /(mg·kg ⁻¹)	SMBC/TOC ratio /%	SMBN/TN ratio /%	SMBP/TP ratio /%	SMBC/SMBN /%	Microbial respiration /(mg·kg ⁻¹ ·day ⁻¹)	qCO ₂ / (mg CO ₂ -Cg ⁻¹ biomass·C·h ⁻¹)
CK	129.42 d	19.02 e	6.73 c	4.72 b	5.21 a	1.23 c	6.80	52.72 d	16.97 a
FL	270.50 c	25.52 de	10.96 ab	4.11 d	3.32 c	1.87 ab	10.60	78.00 b	12.01 b
RP	285.57 c	40.69 ab	10.86 ab	4.81 b	5.56 a	1.77 ab	7.02	66.84 c	9.75 c
CA	304.04 ab	41.29 a	11.33 a	5.30 a	5.82 a	1.97 ab	7.36	71.79 bc	9.84 c
PT	287.53 bc	26.75 d	8.87 bc	4.48 c	4.04 bc	1.55 bc	10.75	73.92 b	10.71 c
PA	316.07 a	34.46 bc	12.11 a	4.63 bc	4.28 b	2.02 a	9.17	96.58 a	12.73 b
RA	313.42 a	31.04 cd	11.67 a	3.38 e	3.53 bc	1.88 ab	10.10	98.90 a	13.15 b

Note: values in the same columns that do not contain the same letters are significantly different at the level of 0.01.

>*P. tabulaeformis*> fallow land. The amplification of SMBP is from 31.79% to 79.94%, followed the order: *P. tabulaeformis*–*A. fruticosa*>*R. pseudoacacia*–*A. fruticosa*>*C. korshinkii*> fallow land >*R. pseudoacacia*. The amplitude of organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) is similar, but the amplitude of SMBN is the largest in *C. korshinkii* and *R. pseudoacacia*, which benefits the growth of azotobacter and mycorrhiza so as to strengthen nitrogen fixation. Soil microbial biomass is sensitive to the change of soil environment and reflects the change of the way of land use and ecological function completely. The microbial biomass of sloping farmland under erosion environment decreased, which is due to human activity, eroded surface soil and aggravating organic material mineralization (Wang et al., 1996; Yang et al., 1999; Song et al., 2002; Zhang et al., 2002). There are tremendous changes in SMBC, organic matter and microbial biomass. However, different types of vegetation restoration are different in improving soil properties, which result in the diversity of the kind and quantity of different microbial communities (Jiang and Zhou, 2003).

Jenkinson (1987) thought that not only the rate of SMBC, SMBN and SMBP to organic carbon, total nitrogen and total phosphorus are considered and the change of soil properties is unveiled in the course of vegetation restoration in the sight of microbiology but also the microbial biomass should be taken into account because it cannot reflect activity, structure and proportion of it absolutely without environmental factor. Table 2 expressed that the rates of SMBC, SMBN and SMBP to the total carbon, total nitrogen and total phosphorus are different through different types of vegetation restoration. The ratio of SMBP to total phosphorus is 1.23%–2.02%, and its amplitude is larger than it in control apparently. The ratio of SMBC and SMBN to organic carbon and organic nitrogen are 3.38%–5.30% and 3.32%–5.82% partly. The organic carbon and total nitrogen of control are lower than those of forest through vegetation restoration, while the amplification of SMBC and SMBN is larger than that of organic carbon and total nitrogen. Therefore, the ratio of SMBC and SMBN to organic carbon and nitrogen in the *C. korshinkii* and *R. pseudoacacia* slightly increases in other restoration types respectively. The diversity of organic matter in the ecosystem results in the variety of microbial communities and biological activity. It was reported that the ratio of SMBC, SMBN and SMBP to organic carbon, total nitrogen and total phosphorus is 0.27%–7.0%, 2%–6% and 0.5%–8.5% respectively (Zeller et al., 2001). The result of this paper is similar to other researches. While the rate of SMBC to organic carbon and the rate of SMBN to total nitrogen are larger and the rate of SMBP to total phosphorus is slightly smaller. The amount of organic carbon and nitrogen on hilly Loess Plateau under erosion environment is little and the cycle of metabolism function of microflora is short, which show that the rate of SMBC and SMBN to organic carbon and total nitrogen should be increased to maintain high quality material cycle and energy flow in order to ensure sufficient carbon, nitrogen and nutritive material so as to maintain vegetation growth.

The rate of SMBC to SMBN can reflect the flora and type of microbial communities (Chen and He, 1998; Wardle, 1998; Huang et al., 2000). Huang et al. (2000) reported that the rate of SMBC to SMBN of bacterium, actinomycetes and fungus is about 5 : 1, 6 : 1 and 10 : 1. The rate of SMBC to SMBN has increased according to the Table 2. It can be concluded that the amplitude of *P. tabulaeformis* is the largest near 10.75 and the amplitude of *R. pseudoacacia* is the smallest about 7.02. The diversity of microbial communities which result from the decomposition of litter fall and root material results in different contents of SMBC/SMBN. The amplification of fungus biomass is larger than bacterium by comparing the SMBC/SMBN of different restoration types, which agrees with the result of Huang et al. (2000).

4.2 Respiration and metabolism quotient of soil

Soil respiration is an important biological index of soil properties and fertility. The soil respiration reveals the transformation and supply capacity of soil nutrition substance and expresses the soil biological properties and matter metabolism capacity. In the course of the vegetation restoration, the change of vegetation affects the soil physical, chemical and biological properties by assimilating nutrition substance and returning organic matter. Moreover, the respiration alters with it, which reveals the involvement of soil properties. According to Table 2, the soil respiration increases dramatically in respect of sloping farmland and its amplification scope is from 26.78% to 87.59% after vegetation restoration, followed the order *R. pseudoacacia*–*A. fruticosa*>*P. tabulaeformis*–*A. fruticosa*> fallow land >*P. tabulaeformis*>*C. korshinkii*>*R. pseudoacacia*, which is the same as the change of organic carbon. Therefore, the soil organic carbon acts on the respiration dramatically. Sparling (1981) thought respiration represented active SMBC, while Anderson and Domsch (1985) considered that respiration revealed the activity of microbial community including dormant and undormant microbial community. It was stated that the most edaphons were in a dormant state and only a little breathed. The research showed that the change of soil respiration and SMBC were not isochronous. The soil respiration can stand for the activity of microbial community and their action principle each other is expected to further study.

Metabolism quotient is the ratio of basic respiration to SMBC and stands for maintain function and utilization efficiency of substrate of microbial community. It is a sensitive index that reflects the influences of the change of environmental factors and management measures on soil activity (Brookes et al., 1985; Brookes, 1995). The higher the efficiency of metabolism quotient, the less the carbon dioxide and the smaller the metabolism quotient. On the contrary, the correspondence is true, which accounts for that microbial biomass produces a little under the same energy, the turnover rate of edaphon is faster and the average age of it is

lower. Table 2 revealed that the metabolism quotient declines obviously with 57.45%–77.49%. The change order of it is the same as the amplification of respiration. The differences among *R. pseudoacacia*–*A. fruticosa*, *P. tabulaeformis*–*A. fruticosa* and fallow land are minuscule, but remarkable among *P. tabulaeformis*, *C. korshinkii* and *R. pseudoacacia*. Odum (1985) concluded that microorganism must separate part of energy of maintaining growth and breeding to compensate additional energy because of stress under the environmental threat. Due to the severe interruption and the declining of soil fertility, there were less energy to keep water and fertility on sloping farmland under erosion environment where edaphon expended additional energy to maintain normal life activity. Therefore, the metabolism quotient was high. After vegetation restoration, the correspondences altered and metabolism quotient declined. The lower the metabolism quotient, the higher the metabolize efficiency. There was better active matter to maintain soil properties and continued using potential preferably. Andrews and Harris (1986) considered that there was little metabolism quotient in soil which have no fresh diffluent organic matter. In this kind of soil, the K strategy microbial community is dominating that has more complex food web. The vegetation species and matter for providing edaphon metabolism have increased and food web of microbial community has got complex to maintain ecosystem.

4.3 Influences of different types of vegetation restoration on soil nutrition substance

Soil can adjust water, fertility, gas, heat and roots space and is affected by environmental factors. The soil properties changed dramatically with the change of ways of land use. The soil nutrition substance has changed remarkably on the sloping farmland after vegetation restoration compared with control (Table 3). The amplification scope of organic carbon, total nitrogen and total phosphorus alkali-hydrolyzable nitrogen, available phosphorus and available potassium were 109%–238%, 82%–141%, 4%–13%, 97%–241%, 8%–70% and 16%–93% respectively. The soil pH value declined remarkably in the types of fallow land, *C. korshinkii* and *R. pseudoacacia*–*A. fruticosa*, while the bulk density and cosmid content of soil increased dramatically in other plots

except fallow land and *C. korshinkii*. Table 3 also showed that the different types of vegetation restoration had different effects in improving soil nutrition substance, the order of effects is given as follows: *R. pseudoacacia*–*A. fruticosa* > *P. tabulaeformis*–*A. fruticosa* > fallow land > pure forests. The three pure forests improved the soil nutrition substance inconspicuously, which resulted from their different biological characteristics.

The farmland field ecosystem of the open or half-open structures of material cycle was transformed into the close or half-close structures of material cycle after vegetation restoration. The soil nutrition substance, water and plant relic returned ecosystem and provided abundant sources to improve and supply soil nutrition substance. Especially, the increase in microbial biomass and activity accelerated matter metabolism and promoted the accumulation of nutrition substance. The soil nutrition substance increased, but the accumulation of different nutrient elements was different, which resulted from the different biomass of litter fall, chemical constituent and decomposition speed. The soil nutrition substance of mixed forest accumulated dramatically because of the abundance of vegetation species and roots system. Moreover, because a great deal dead roots provided abundant nutrition substance and improved soil physical structure by organic cement, the majority of biomass returned soil after withering on the uneven ground where there were annual or vivacious herbs. However, the accumulation of nutrition substance on the uneven ground was less than that in the mixed forest because of blazing illumination, low soil water content and slow litter decomposition. The returned biomass of pure forest was large, while the effects on improving soil nutrition substance were lower than those on the above two plots. That was because pure forest expended more nutrition substance. The deadwood and defoliation of *P. tabulaeformis* contained a number of resinous macromolecule organic matter that was not decomposed sufficiently by edaphon and was accumulated at the forest floor perennially. Moreover, it increased moisture content of soil and provided benign environment to edaphon to accelerate substance dissociation and accumulate soil nutrition substance. The litter fall of *R. pseudoacacia* and *C. korshinkii* was decomposed fast and absorbed quickly by vegetation so that the accumulation of organic carbon in them

Table 3 Characteristics of soil in different sites ($n = 3$)

Item	Organic C /(g·kg ⁻¹)	Total N /(g·kg ⁻¹)	Available N /(mg·kg ⁻¹)	Total P /(g·kg ⁻¹)	Available P /(g·kg ⁻¹)	C/N ratio	Available K/(g·kg ⁻¹)	pH (H ₂ O, 1:2.5)	Bulk density /(g·cm ⁻³)	Soil size fraction distribution		
										Clay /%	Silt /%	Sand /%
CK	2.74 e	0.365 f	20.90 e	0.55 d	1.64 d	7.51	105.4 g	8.73 a	1.17 bc	3.07 cd	14.85 d	82.08 a
FL	6.59 bc	0.769 bc	50.77 b	0.59 bc	2.44 ab	8.57	162.7 e	8.70 b	1.28 a	3.00 d	15.95 c	81.05 ab
RP	5.94 d	0.731 cd	41.48 d	0.61 ab	1.97 bcd	8.12	174.3 c	8.74 a	1.08 de	3.70 a	17.68 a	78.62 c
CA	5.74 d	0.710 d	45.12 cd	0.58 c	2.32 abc	8.08	192.3 b	8.70 b	1.19 b	2.99 d	14.61 d	82.13 a
PT	6.42 c	0.663 e	41.14 d	0.57 c	1.77 abc	9.68	122.7 f	8.74 a	1.11 d	3.14 bc	16.67 bc	78.83 c
PA	6.83 b	0.806 b	46.12 c	0.60 abc	2.40 cd	8.47	168.3 d	8.73 a	1.06 e	3.25 b	16.97 ab	78.30 c
RA	9.27 a	0.880 a	71.34 a	0.62 a	2.79 a	10.53	203.6 a	8.62 c	1.15 c	3.25 b	15.95 c	80.80 b

Note: Values in the same columns that do not contain the same letters are significantly different at the 1% level.

Table 4 Correlation coefficient among microbial biomass, respiration strength, qCO₂ values and characteristics of soil

R	SMBC	SMBN	SMBP	SMBC /SMBN	Microbial respiration	Metabolic quotient	Organic C	Total N	Available N	Total P	Available P	Available K
SMBC	1.000	0.707	0.891**	0.461	0.766*	-0.666	0.841*	0.928**	0.766*	0.747	0.666	0.763*
SMBN		1.000	0.721	-0.292	0.268	-0.653	0.353	0.561	0.334	0.585	0.345	0.742
SMBP			1.000	0.277	0.785*	-0.415	0.773*	0.938**	0.772*	0.843*	0.841*	0.900**
SMBC/SMBN				1.000	0.622	-0.177	0.667	0.536	0.590	0.250	0.419	0.078
Respiration					1.000	-0.058	0.894**	0.871**	0.848**	0.736	0.840*	0.647
qCO ₂						1.000	-0.361	-0.455	-0.292	-0.306	-0.069	-0.386

Note: * and ** mean significant difference at $p < 0.05$ and $p < 0.01$ levels, respectively.

cannot match the accumulation of organic carbon in the *P. tabulaeformis*. However, they can produce azotobacter and increase the nitrogen contents to decline soil C/N, which was similar to other researches (Beijing Forestry University, 1982).

4.4 Coupling between soil nutrition substance and microbial biomass and respiration of soil

The significant relationships were observed among microbial biomass, respiration and physical and chemical properties. The microbial biomass, respiration and fertility factor were analyzed (Table 4). The SMBC had a connection with the SMBP, respiration, organic carbon, total nitrogen, alkali-hydrolyzable nitrogen and available potassium dramatically. The SMBP had a connection with respiration, organic carbon, total nitrogen, alkali-hydrolyzable nitrogen, total phosphorus, available phosphorus and available potassium besides the SMBC remarkably. However, the respiration had a connection with the SMBC, the SMBP, organic carbon, total nitrogen, alkali-hydrolyzable nitrogen and available potassium significantly. The SMBC and SMBN had obvious relationships in previous researches, while they were just correlative but connection was not remarkable in this research. It is because that the microbial community was diverse, which results in the diversity of fixing, distribution and inversion of nitrogen. Therefore, it was feasible and cooperative that the SMBC and SMBP were regarded as biological indices of soil properties.

5 Conclusions

1) After vegetation restoration, the microbial biomass was improved dramatically on sloping farmland under erosion environment. The increases in the SMBC, SMBN and SMBP were 109.01%–144.22%, 34.17%–17.09% and 31.79%–79.94% respectively. Compared with the control, the ratio of the SMBP to total phosphorus increased remarkably, while the ratio of SMBC and SMBC to organic carbon and total nitrogen declined slightly in *R. pseudoacacia* and *C. korshinkii*. The ratio of the SMBC to SMBN increased, which indicated that the amplification of fungus biomass was more than bacterium biomass after vegetation restoration.

2) After vegetation restoration, the soil respiration strengthened obviously, while the metabolize quotient declined

remarkably. The vegetation species and matter for providing edaphon metabolism has increased and food web of microbial community got complex to maintain ecology system.

3) After vegetation restoration, the physical and chemical properties of soil increased apparently, and the organic carbon, total nitrogen, total phosphorus, alkali-hydrolyzable nitrogen, available phosphorus and available potassium also increased. The different types of vegetation restoration resulted in different effects on improving soil nutrition substance, the order of effects was given as follows: *R. pseudoacacia*–*A. fruticosa* > *P. tabulaeformis*–*A. fruticosa* > fallow land > pure forests. The three pure forests slightly improved the soil nutrition substance, which resulted from their different biological characteristics. The SMBC, SMBN and respiration closely related with physical and chemical properties of soil. The SMBC and SMBP can be regarded as biological indices of soil properties.

4) On the eroded hilly Loess Plateau, the soil nutrition substance and the microbial biomass contents are low and the cycle period of metabolism act is short. More measures of converting cultivated land must be taken to forest and grassland and restoration where the mixed forest is dominating and the pure forest is subsidiary to maintain the healthy development of the ecosystem.

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