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## Evolution of soil microbial biomass in restoration process of *Robinia pseudoacacia* plantations in an eroded environment

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**Abstract** Vegetation recovery is a key measure to improve ecosystems in the Loess Plateau in China. To understand the evolution of soil microorganisms in forest plantations in the hilly areas of the Loess Plateau, the soil microbial biomass, microbial respiration and physical and chemical properties of the soil of *Robinia pseudoacacia* plantations were studied. In this study, eight forest soils of different age classes were used to study the evolution of soil microbial biomass, while a farmland and a native forest community of *Platycladus orientalis* L. were chosen as controls. By measuring soil microbial biomass, metabolic quotient, and physical and chemical properties, it can be concluded that soil quality was improved steadily after planting. Soil microbial biomass of C, N and P (SMBC, SMBN and SMBP) increased significantly after 10 to 15 years of afforestation and vegetation recovery. A relatively stable state of soil microbial biomass was maintained in near-mature or mature plantations. There was an increase of soil microbial biomass appearing at the end of the mature stage. After 50 years of afforestation and vegetation recovery, compared with those in farmland, the soil microbial biomass of C, N and P increased by 213%, 201% and 83% respectively, but only accounting for 51%, 55% and 61% of the increase in *P. orientalis* forest. Microbial soil respiration was enhanced in the early stages, and then weakened in the later stage after restoration, which was different from the change of soil

organic carbon. The metabolic quotient ( $q\text{CO}_2$ ) was significantly higher in the soils of the *P. orientalis* forest than that in farmland at the early restoration stage and then decreased rapidly. After 25 years of afforestation and vegetation recovery,  $q\text{CO}_2$  in soils of the *R. pseudoacacia* forest was lower than that in the farmland soil, and reached a minimum after 50 years, which was close to that of the *P. orientalis* forest. A significant relationship was found among soil microbial biomass,  $q\text{CO}_2$  and physical and chemical properties and restoration duration. Therefore, we conclude that it is possible to artificially improve the ecological environment and soil quality in the hilly area of the Loess Plateau; a long time, even more than 100 years, is needed to reach the climax of the present natural forest.

**Keywords** erosion environment, *Robinia pseudoacacia*, ecological restoration, soil microbial biomass, soil quality

### 1 Introduction

Eroded environment gives rise to a special landscape where the ecology is seriously deteriorating because of soil erosion. It is a multiple environmental system that is subject to natural erosion and anthropogenic activities leading to erosion of the environment. Vegetation restoration is an important way to improve the environment of the hilly Loess Plateau, a seriously eroded region where efforts are being made to put the Project of Converting Farmland to Forest and Grassland into practice. Vegetation restoration can improve soil properties, and control soil and water losses. Soil microorganisms are important variables and driving forces in the material cycle and energy flows, like nutrition circulation, decomposition of organic matter and other ecological processes. These variables on soil microorganisms had been used for establishing relationships between soil microbial biomass and recovery functions of degraded ecosystems (Harris, 2003). Elements of soil microbial biomass of C, N and P (SMBC, SMBN and SMBP) form a pool of active

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nutritional soil substances, and are important sources for plant growth. Moreover, these elements can reflect the sensitivity of changes in environmental factors and land use types because of their short cycles. Generally, soil microbial biomass is considered as one of the more important evaluation indices of soil properties (Paul and Voroney, 1980; Jenkinson and Ladd, 1981; Powlson et al., 1987; Ross, 1990; Anderson and Dormsch, 1993; Sparling and Ross, 1993; Rogers and Tate, 2001).

Many studies show that planting can improve soil properties and maintain soil fertility through secondary succession during the process of reestablishment of species and restoration of soil fertility. Changes in soil microorganisms have a significant effect on this process (Campbell et al., 1994; Lamb, 1998). At present, some scholars are studying the change of physical and chemical properties of soils after vegetation restoration (Gong et al., 2005; Jiao et al., 2005), but the evolution of soil microbial biomass is not reported often. We studied the development of soil quality by means of soil microorganisms in stands of *Robinia pseudoacacia* in different age classes to evaluate the effect of soil quality restoration and to offer a basis for rebuilding of vegetation communities.

## 2 Study site

Our study was carried out in the Zhifanggou Watershed, belonging to the Ansai Research Station of Soil and Water Conservation, located in the semi-arid region of the Loess Plateau (36°46'28"–36°46'42"N, 109°13'03"–109°16'46"E). It belongs to a typically hilly and gully loess region at an elevation of 1010–1400 m. The area is dominated by a warm temperate continental monsoon climate, and has a severe spring drought occurring every year. The mean annual temperature is 8.8°C, while annual precipitation is 505.3 mm. The station was established in 1973 to monitor the long-term ecological environment, because its environment had been destroyed severely by human activities. The ecosystem in this region has passed through five stages: a stage of severe damage (1938–1958), a stage of

sustained damage (1959–1973), an unstable stage (1974–1983), a restoration stage (1983–1990) and a stage of a benign ecological system (1991–present). A system of restoration and regeneration of the vegetation was adopted to control soil and water loss and to restore the degraded ecosystem. The forest coverage in the entire watershed increased dramatically from 5% to 40% and a healthy economic ecology system has been developing after 30 years of comprehensive control (Liu, 1999).

In order to understand the evolution of soil microbial characteristics of artificial forests in this region, by substituting temporal series for spatial series, we studied eight soils of *R. pseudoacacia* plantations of different ages. A farmland plot (CK) and a native forest of *Platycladus orientalis* L. (PO) were selected as controls. The eight *R. pseudoacacia* plantations sites consist of a 5-year-old stand (RP5), a 10-year-old stand (RP10), a 15-year-old stand (RP15), a 20-year-old stand (RP20), a 25-year-old stand (RP25), a 30-year-old stand (RP30), a 40-year-old stand (RP40) and a 50-year-old stand (RP50) (Table 1).

## 3 Sample collection and analysis

In July 2005, soil samples from 0 to 20 cm soil layer along an "S" type pattern at each trial site were collected and mixed. The soil samples were divided into two groups. One group was used to determine soil microbial biomass by a chloroform fumigation-extraction method (He, 1994; Horwath and Paul, 1994) and respiration intensity by lye assimilation (Xu and Zheng, 1986). We determined SMBC, SMBN and SMBP by using a Tekmar-Dohrmann Apollo 9000 TOC Combustion Analyzer, continuous flowing analyzer and molybdenum stibium anti-spectrophotometry. The other group was used to measure soil chemical properties, including the pH value, total nitrogen, total phosphorus, organic matter, available phosphorus and available potassium, after air drying and sieving of 1 mm or 0.25 mm (Lu, 1999). Analysis of variance (ANOVA) and a correlation analysis were carried out by SAS 6.12.

**Table 1** Basic information of sample plots of different age class forest stands

sites	age	landform	exposure	slope gradient/°	elevation/m	soil type	undergrowth vegetation
CK	0	HS	N	22	1175	loess	<i>Setaria italic</i> (L.)
RP5	5	HS	NW35°	21	1198	loess	<i>Achillea capillaries</i>
RP10	10	HS	W	21	1171	loess	<i>Stipa bungeana</i>
RP15	15	HS	N	30	1150	loess	<i>Melica scabrosa</i> – <i>Stipa bungeana</i>
RP20	20	HS	N45°W	24	1029	loess	<i>Artemisia sacrorum</i> – <i>Stipa bungeana</i>
RP25	25	HS	NW45°	28	1249	loess	<i>Artemisia sacrorum</i> – <i>Stipa bungeana</i>
RP30	30	HS	NE10°	32	1129	loess	<i>Lespedeza dahurica</i> – <i>Stipa bungeana</i>
RP40	40	HS	N	25	1172	loess	<i>Artemisia sacrorum</i> – <i>Stipa bungeana</i>
RP50	50	GS	E	23	1183	loess	<i>Artemisia sacrorum</i> – <i>Stipa bungeana</i>
PO	–	HS	N1°W	33	1283	loess	<i>Carex lanceolat</i>

Note: HS means hillside and GS gully slope.

## 4 Results and analysis

### 4.1 Effects of vegetation restoration on soil nutrition

Farming practices led to carbon and nitrogen loss while vegetation restoration can increase their levels from root exudates and litter, which affects the material cycle in the soil and can improve soil quality (Rutigliano et al., 2004). There was a significant change in the physical and chemical properties of the soil as a result of vegetation restoration. Compared with farmland, the amounts of organic carbon, total nitrogen, available nitrogen, available phosphorus and available potassium had no significant increase or even dropped slightly during the first five years after establishment of the *R. pseudoacacia* plantation. Then, the amounts increased gradually with the extension of plant restoration, reaching their highest levels after 10 to 25 years, and remained relatively stable during this stage. After 30 to 40 years, the amounts varied slightly. Total phosphorus, pH value and bulk density did not increase until 10 years after planting. After 50 years of afforestation and vegetation recovery, the organic carbon increased by 272%, total nitrogen by 185%, and available nitrogen by 275%; the amount of available phosphorus doubled and available potassium increased by 82% compared with the farmland, but bulk density dropped by 30%. However, the amount of organic carbon and total nitrogen in the soil of the *P. orientalis* community were only 49% and 55% compared with the farmland while the bulk density was 25% higher (Table 2).

The ecosystem of open or half-open material cycle structures of farmland has been transformed into closed or half-closed structures after vegetation restoration. The amount of litter and dead branches returned to the system provided an abundant source of matter to improve and supply soil nutrients, and were decomposed to humus by soil microorganism, which increased soil organic matter. On the other hand, nitrogen in the air was fixed in the soil to improve soil properties and provided more nutrition for the restored vegetation. Moreover, the coverage of soil surface increased as a result of vegetation restoration,

which effectively prevented or eased the incidence of wind and water erosion and reduced the loss in soil nutrition.

The soil properties changed with plant growth during vegetation restoration. During the early stages of *R. pseudoacacia*, the amount of vegetation biomass was small, because the amounts of accumulated soil nutrients and litter returned to the soil were small. During the middle and early mature stages, the rapid growth of the *R. pseudoacacia* plantations led to the increase of the nutrition amount and soil coverage, and soil erosion degree and nutrition loss decreased rapidly. Gradually, a dry soil layer was formed and nutrient accumulation declined slightly at the mature stage of the plantation, which resulted in a decrease in the physiological functions of the vegetation in the last few years of this stage. However, the condition of the soil nutrients improved over many years, providing a better environment for subsequent succession species in the *R. pseudoacacia* plantations. All of the factors (multiple layers of the forest story, initial formation of forest patches, species richness, and especially the appearance of mosses), contributed considerably to the improvement of soil properties. Compared with the secondary *P. orientalis* forest, there was a certain gap in the concentration of soil nutrition and it took a long time to reach the level of a climax community in this region. The results suggest that it is possible to improve the environment and soil quality in the hilly area of the Loess Plateau by self-fertilization. It is possible to restore a healthy natural vegetation and beautiful landscape from past damage through proper management practices.

### 4.2 Evolution characteristics of soil microbial biomass

Soil microbial biomass is the total amount of active organic matter with a volume less than  $5 \times 10^3 \mu\text{m}^3$ . It is also an important parameter of soil fertility characteristics and the driving force of the material cycle and energy flows. Soil microbial biomass C, P and N increased dramatically after 10 to 15 years plantation of *R. pseudoacacia*, while a relatively stable state was maintained in the

**Table 2** Characteristics of different soils during different vegetation restoration periods

sites	organic C/g·kg <sup>-1</sup>	total N/g·kg <sup>-1</sup>	available N/mg·kg <sup>-1</sup>	total P/g·kg <sup>-1</sup>	available P/mg·kg <sup>-1</sup>	C/N ratio	available K/mg·kg <sup>-1</sup>	pH	bulk density/ g·cm <sup>-3</sup>
CK	2.74 g	0.365 g	20.90 g	0.549 e	1.64 d	7.51	105.4 h	8.73 c	1.17 c
RP5	2.81 g	0.357 g	17.59 h	0.486 g	1.57 d	7.87	118.2 g	8.84 a	1.28 a
RP10	3.69 f	0.453 f	35.50 f	0.505 f	1.83 d	8.15	144.1 f	8.76bc	1.23 ab
RP15	6.44 c	0.670 e	60.4 c	0.568 d	3.59 b	9.61	169.1 d	8.62 d	1.16 c
RP20	6.52 c	0.710 cd	59.06 c	0.560 de	3.46 a	9.18	193.1 b	8.44 g	1.08 d
RP25	5.93 d	0.702 d	58.73 c	0.572 cd	2.54 c	8.45	202.9 a	8.77 b	1.08 d
RP30	5.94 d	0.731 c	41.48 e	0.614 a	1.97 d	8.13	174.3 c	8.74 bc	1.04 d
RP40	5.57 e	0.700 d	46.78 d	0.585 bc	2.67 c	7.96	192.5 b	8.53 e	0.93 e
RP50	10.18 b	1.041 b	78.30 b	0.594 b	3.30 b	9.78	161.3 e	8.43 g	0.90 e
PO	20.80 a	1.894 a	109.5 a	0.613 a	3.53 b	10.98	194.7 b	8.47 f	0.72 f

Note: Values in the same columns with different letters means significantly difference at 1% level.

early mature or mature forest with an increase at the end of the mature stage. After 50 years of vegetation restoration, the microbial biomass of C increased 213%, N 201% and P 83%, compared with that of the farmland, but only 51%, 55%, and 61% of that in the soil of the *P. orientalis* community (Table 3). Microbial biomass is sensitive to changes in the soil environment and completely reflects changes in land use and ecological functions. The microbial biomass in the sloping and eroded farmland decreased, which is due to anthropogenic activities, eroded soil surfaces and aggravating mineralization of organic matter (Wang et al., 1996; Yang et al., 1999; Zhang et al., 2002). There were tremendous changes in microbial biomass and organic matter. Jia et al. (2005) argued that microbial biomass increased during the process of vegetation growth and reached its maximum at age 17, then declined and remained relatively stable afterwards. Our research results are similar to those of Jia et al. (2005), but the soil microbial biomass increased again at the end of restoration. The pioneer species probably provided a better ecological environment for the development of the vegetation during the process of succession, which promoted the growth and development of later succession species and the ecosystem. However, the microbial biomass after 50 years was still lower than that of the climax community, which means it is far more difficult to repair a natural environment than to destroy it.

Jenkinson (1987) thought that soil microbial biomass cannot reflect its activity, structure and proportion in an absolute sense without environmental factors, so the ratios of SMBC, SMBN and SMBP to organic carbon, total nitrogen and total phosphorus should be considered and changes in soil properties exposed in the course of restoration vegetation from a microbiology point of view. In Table 2, we can see that the ratios of SMBC, SMBN and SMBP to total carbon, total nitrogen and total phosphorus varied across different periods of the course of restoration. It was reported that the ratios of SMBC, SMBN and SMBP to organic carbon, total nitrogen and total phosphorus ranged between 0.27%–7.0%, 2%–6%

and 0.5%–8.5% respectively (Zeller et al., 2001). Our respective ratios turned out to range between 3.58%–5.84%, 5.51%–6.81% and 1.29%–2.34%, which is similar to that of other investigations but the ratio of SMBC to organic carbon and the ratio of SMBN to total nitrogen were larger and the ratio of SMBP to total phosphorus was slightly smaller than results from Zeller et al. (2001). The amounts of organic carbon and nitrogen in the eroded environment of the hilly Loess Plateau is small and the cycle of metabolism functions of the microorganisms short, which shows that the ratio of SMBC and SMBN to organic carbon and total nitrogen should be increased to maintain a high quality material cycle and energy flows. This should ensure sufficient carbon, nitrogen and nutritive material in order to maintain vegetation growth. The metabolic quotient (*q*MB) of soil microbial biomass was affected by the quality and amount of organic material and can be effectively monitored by soil microbial biomass (Srivastava and Singh, 1991; Garcia et al., 2002). *q*MB was higher in the sloping farmland than in the *R. pseudoacacia* plantations, and increased at the early phase of rapid vegetation growth, so the higher *q*MB needs a highly efficient material cycle and energy flows (Table 3). During the mature stage, secondary forest patches appeared and the amount of available nutrition increased gradually, which resulted in non-active carbon and caused the *q*MB to drop significantly (Bauhus et al., 1998; Landgraf, 2001).

The ratio of SMBC to SMBN reflected the flora and type of microbial communities (Chen and Huang, 1998; Wardle, 1998; Huang et al., 2000). Huang et al. (2000) reported that the ratios of SMBC to SMBN of bacteria, actinomycetes and fungi were about 5:1, 6:1 and 10:1. The ratio of SMBC to SMBN was below 6:1 in the early years of the *R. pseudoacacia* plantation (Table 3), lower than that of farmland, which indicated that the concentration of bacteria in the early years is far higher than that in the middle and late stages in the total accumulation of soil microorganisms. The diversity of microbial communities from the decomposition of litter and root material resulted in changes of the microflora.

**Table 3** Microbial biomasses, respiration strengths and *q*MB values of soils in different vegetation restoration periods

plot	SMBC/ mg·kg <sup>-1</sup>	SMBN/ mg·kg <sup>-1</sup>	SMBP/ mg·kg <sup>-1</sup>	SMBC/ TOC/%	SMBN/TN/%	SMBP/TP/%	SMBC/ SMBN/%	microbial respiration/ mg·kg <sup>-1</sup> ·d <sup>-1</sup>	<i>q</i> MB/mgCO <sub>2</sub> ·g SMBC <sup>-1</sup> ·h <sup>-1</sup>
CK	129.42 g	19.02 d	6.73 f	4.72 b	5.21 c	1.23 e	6.80	52.7 e	16.97 e
RP5	121.06 g	24.31 d	6.66 f	4.31 bcd	6.81 a	1.37 e	4.98	107.5 c	37.00 a
RP10	159.51 f	27.44 d	6.53 f	4.32 bcd	6.06 abc	1.29 e	5.81	120.5 b	31.48 b
RP15	282.69 e	37.65 c	9.92 e	4.39 bc	5.62 bc	1.75 d	7.51	166.7 a	25.40 c
RP20	307.05 cd	41.44 c	13.10 b	4.71 b	5.84 ab	2.34 b	7.41	170.0 a	23.52 cd
RP25	274.71 e	43.72 c	11.71 cd	4.63 b	6.23 ab	2.05 c	6.28	133.1 b	20.19 de
RP30	285.57 de	40.69 c	10.86 de	4.81 b	5.57 bc	1.77 d	7.02	66.8 d	9.75 f
RP40	325.16 c	39.54 c	9.90 e	5.84 a	5.65 bc	1.69 d	8.22	56.3 de	7.21 fg
RP50	404.76 b	57.32 b	12.29 bc	3.98 cd	5.51 bc	2.07 c	7.06	54.8 e	5.64 g
PO	793.91 a	103.89 a	19.99 a	3.82 d	5.49 bc	3.26 a	7.64	102.6 c	5.38 g

Note: Values in the same columns with different letters means significant difference at the 1% level.

### 4.3 Respiration and soil metabolism quotient

Soil respiration is an important biological index of soil property and fertility. Soil respiration reveals the transformation and supply capacity of soil nutrition and expresses biological soil properties and the capacity for metabolism of matter. Over the course of vegetation restoration, the change of vegetation affected the physical, chemical and biological properties of the soil by assimilating nutrition and returned organic matter. Moreover, the respiration altered with these changes, which suggests evolving soil properties. Compared with the sloping farmland, soil respiration of the *R. pseudoacacia* plantations increased significantly after five years, reached its maximum at 15 to 20 years, then slowed down and reached its lowest point after 50 years, which was lower than that of farmland (Table 3). At the same time, it was found that the change in soil respiration did not follow a pattern similar to that of organic carbon, which shows that organic carbon in the soil had a great effect on respiration. Sparling (1981) thought that respiration represented a change in active SMBC, while Anderson and Domsch (1985) considered that respiration showed the activity of the microbial community including both dormant and active microbial communities. They stated that most microorganisms were in a dormant state and did not breathe much. Our research showed that the changes of soil respiration and SMBC were not isochronous. The soil respiration can represent the activity of microbial community, and their principal actions between each other need further study.

The metabolism quotient ( $q\text{CO}_2$ ) is the ratio of basic respiration to SMBC and stands for sustainable function and utilization efficiency of substrates of microbial communities. It is a sensitive index that reflects the effect of the change of environmental factors and management measures on soil activity (Brookes et al., 1985; Brookes, 1995). The higher the efficiency of the metabolism quotient, the lower the amount of carbon dioxide and the smaller the metabolism quotient itself. Vice versa, the microbial biomass produced little with the same amount of energy, the turnover rate of microflora was fast and its average age was low. Our research revealed that, at the beginning of the vegetation restoration period, the metabolism quotient sharply increased and then decreased during subsequent

extension of the restoration project. After 25 years of afforestation and vegetation recovery,  $q\text{CO}_2$  was lower than that in the farmland and reached a minimum after 50 years, which is close to that of the *P. orientalis* community. Odum (1985) concluded that microorganisms separated part of their energy requirements from the energy used for maintaining growth and breeding to compensate for the additional energy because of stress induced under environmental threats. Due to the severe interruption and decline in soil fertility, there was less energy to maintain water and fertility on the sloping farmland under stress of erosion where additional edaphic energy was expended to maintain normal life activities. Thus, the metabolism quotient was high. After vegetation restoration, the metabolism quotient declined with lessening interruption. The lower the metabolism quotient, the higher the efficiency of metabolizing. There are better active substances to maintain soil properties, which by preference continue to use the potential. Andrews and Harris (1986) considered that the metabolism quotient in the soil was small when there was no fresh diffuent organic matter. In this kind of soil, the microbial community of *K*-selection is a dominant community that has a more complex food web. These results imply that the number of species and matter for providing edaphic metabolism increase and the food web of the microbial community has become too complex to maintain the ecosystem in the Loess Plateau after the establishment of the *R. pseudoacacia* plantations.

### 4.4 Coupling between soil nutrition, microbial biomass and respiration of soil

We analyzed the relationship among microbial biomass, respiration and fertility factors (Table 4). The important relationships observed among the microbial biomass of C, N and P are also closely related to organic carbon, total nitrogen, available nitrogen and total phosphorus, while the metabolism quotient has a negative relation with microbial biomass, total nitrogen and total phosphorus. Respiration has only a tenuous connection with other factors that were statistically not significant. Because soil microbial biomass has a close relationship with soil nutrition during the process of vegetation restoration, microbial biomass of C, N and P and the metabolism quotient can be regarded as biological indices of soil quality. It also

**Table 4** Correlation coefficients of microbial biomass, respiration strengths,  $q\text{CO}_2$  values and soil characteristics ( $n = 10$ )

<i>R</i>	SMBC	SMBN	SMBP	respiration	$q\text{CO}_2$	years	TOC	TN	available N	TP	available P	available K
SMBC	1.000	0.991**	0.957**	-0.025	-0.665*	0.891**	0.987**	0.994**	0.938**	0.697*	0.555	0.606
SMBN		1.000	0.955**	-0.005	-0.614	0.874**	0.992**	0.997**	0.939**	0.645*	0.515	0.586
SMBP			1.000	0.124	-0.612	0.634	0.938**	0.949**	0.934**	0.711*	0.613	0.709*
respiration				1.000	0.593	-0.679	-0.008	-0.048	0.151	-0.276	0.394	0.313
$q\text{CO}_2$					1.000	-0.962**	-0.597	-0.653*	-0.595	-0.909**	-0.359	-0.456
years						1.000	0.809*	0.892**	0.674	0.799*	0.436	0.485

Note: Coefficients labeled \* and \*\* indicate significant correlation at  $p = 0.05$  and  $p = 0.01$  respectively.

shows that the microbial biomass of C, N and P and the metabolism quotient have a clear relationship with the vegetation restoration years. From this it can be inferred that the annual rate of acceleration of microbial C biomass is 5.62 mg/kg, that of N biomass 0.640 mg/kg, of organic carbon 0.119 g/kg, of total nitrogen 0.012 g/kg, of total phosphorus 0.002 g/kg, while the metabolism quotient actually declines at a rate of 0.52 mg CO<sub>2</sub>/(g SMBC·h) during the process of vegetation restoration. The results suggest that it is possible to artificially improve the ecological environment and soil quality in the eroded, hilly Loess Plateau through vegetation recovery, but it is more difficult to reach the level of soil climax than to destroy it (Shi and Tang, 1996; Zha and Huang, 2001). The time period of restoration is long, perhaps more than 100 years. Therefore, further studies about forest management and the introduction of subsequent species should benefit the process of ecological restoration.

## 5 Conclusions

1) After the establishment of *R. pseudoacacia* plantations, the physical and chemical properties of the soil were improved considerably. The amounts of organic carbon, total nitrogen, available nitrogen, available phosphorus and available potassium increased, respectively, by 272%, 185%, 275%, 101% and 82% compared with the sloping farmland after 50 years of restoration, while the bulk density and pH value sharply decreased. However, the amount of organic carbon was only 49% and that of total nitrogen only 55% of that in the soil of the *P. orientalis* forest community, while the bulk density was 25% higher.

2) Soil microbial biomass changed significantly with vegetation restoration. Soil microbial biomass C, P and N increased dramatically after 10 to 15 years establishment of the *R. pseudoacacia* plantations. A relatively stable state was maintained in nearly mature or mature plantation, but an increase appeared again at the end of the mature stage. After 50 years of vegetation restoration soil microbial biomass of C increased by 213%, that of N by 201% and that of P by 83% compared with the farmland soil. However, they are only 51%, 55%, and 61% of that in the soil of the *P. orientalis* forest.

3) The change of soil respiration increased in the early stages of restoration and decreased during later few years, a pattern dissimilar to that of organic carbon. The metabolism quotient sharply increased at the beginning of the vegetation restoration, but decreased during a subsequent extension of the restoration period. After 50 years of restoration, *q*CO<sub>2</sub> reached its minimum which is close to that of the *P. orientalis* forest community.

4) Significant relations were found among soil microbial biomass, *q*CO<sub>2</sub> and physical and chemical properties

and the time required for restoration. Our results suggest that microbial biomass of C, N and P and the metabolism quotient can be regarded as biological indices of soil quality.

5) It is possible to improve ecological environment and soil quality in the hilly areas of the Loess Plateau by self-fertilization of vegetation, but it will take a long time, perhaps more than 100 years, to reach a climax equal to the original vegetation. Therefore, further studies in such areas on forest management and the introduction of successor species should be carried out from the viewpoint of accelerating the introduction of vegetation during the course of restoration. Proper forest management practices must be applied for healthy natural vegetation and beautiful landscape.

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