Front. For. China 2009, 4(3): 344–350
DOI 10.1007/s11461-009-0051-1

RESEARCH ARTICLE

Gang FU, Zengwen LIU, Fangfang CUI

Features of soil enzyme activities and the number of microorganisms in plantations and their relationships with soil nutrients in the Qinling Mountains, China

Abstract We studied the distribution of soil nutrients, the number of soil microorganisms, soil enzyme activities, and their relationships in pure and mixed plantations. Soil enzyme activities, the number of soil microorganisms, and soil nutrients were measured in plantations of Chinese pine (*Pinustabulaeformis*), larch (*Larix kaempferi*), sharp tooth oak (*Quercus aliena* var. *acuteserrata*), Manchurian catalpa (*Catalpa fargesii*), and mixed plantations in the Qinling Mountains, China. Compared with pure plantations, the conifer-broad-leaved broadleaf mixed plantations increased total N, available N, total P, available K, and organic matter in the forest soil; promoted the activities of invertase and urease by 16.7% and 53.8%; and increased the total amount of soil microorganisms by 95.9% and the number of bacteria by 104.5% ($p < 0.05$). The correlations between soil enzymes, number of microorganisms, and soil nutrients were significant ($p < 0.05$), and the correlations between the number of soil bacteria and basic nutrient prosperities (total N, available N, available K, and organic matter (OM)) were significant or highly significant. The correlations between the number of soil actinomycetes, and soil total N, available N, OM, and pH were also significant or highly significant. A suitable mixture of planted conifers and broad-leaved species improves the quality and amount of soil nutrients, increases the number of soil microorganisms and changes their redistribution. The change of soil enzymes and the number of soil microorganisms are indications of the change tendency of soil nutrients.

Keywords Qinling Mountains, mixed plantations, soil enzyme activity, soil microorganisms, soil nutrients

Translated from *Journal of Northwest A&F University* (*Nat. Sci. Ed.*), 2008, 36(10): 88–94 [译自: 西北农林科技大学学报]

Gang FU, Zengwen LIU (✉), Fangfang CUI
College of Resources and Environment, Northwest A&F University, Yangling 712100, China
E-mail: fg2002075@yahoo.com.cn

1 Introduction

Forest soils, which are considered to be the "pool" for food storage and the "source" of soil nutrients, are closely related to soil microorganisms and enzyme activities (Jiao et al., 1997; Xu et al., 2000; Chen et al., 2002). There are various tree species and management patterns of plantations, so the amount and distribution of soil microorganisms and enzyme activity vary. Studies on features of soil enzyme activity and the number of soil microorganisms are important for understanding the status of soil nutrients in plantations (Xu et al., 2000; Xue et al., 2003). Some problems, such as soil degradation, arise in the growth and development process of pure plantations (Jha et al., 1992; Liu and Li, 2003; Liu et al., 2005); however, we can improve the soil by establishing plantations of mixed species and by stand conversion. Thus, it is necessary for us to study features of soil enzyme activity and the number of soil microorganisms under conditions of pure monoculture plantations and stands of mixed species and their relationships with soil nutrients (Proscott, 1996; Hart et al., 1997; Jiang et al., 2001). Such studies are rare in the Qinling Mountains, a large area of a special forest zone in Western China.

We have studied soil enzyme activities, soil microorganisms, and nutrients of the soil surface in the pure plantations and mixed forests in the Qinling Mountain area. These studies should provide a theoretical basis for us to transform pure plantation in a suitable manner.

2 Study area

Our study was carried out in the Angou Watershed, upstream of the Heihe River in the Qinling Mountains. This watershed is located in the middle of the Qinling Mountains, consisting mostly of steep slopes with mountain cinnamon soils. This area has a warm temperature climate with an average annual precipitation of

900 mm mainly falling in the period of July to September, a short and cool summer, a microthermal and wet fall, and a long and cold winter. The terrain of this region is irregular, and the elevation varies from 1524 to 2904 m. *Quercus variabilis* is the main species in the natural vegetation. Besides coniferous trees such as *Larix kaempferi* and *Pinus tabulaeformis*, the most frequently occurring deciduous species are *Catalpa fargesii* and *Q. aliena* var. *acute-serrata*.

3 Materials and methods

3.1 Sampling design and collection of soil samples

We chose several plantations and mixed plantations of species such as *L. kaempferi*, *P. tabulaeformis*, *C. fargesii*, *Q. aliena* var. *acuteserrata*, *P. tabulaeformis*×*L. kaempferi*, *P. tabulaeformis*×*Q. aliena* var. *acuteserrata*, *L. kaempferi* ×*Q. aliena* var. *acuteserrata*, *and P. tabulaeformis*× *C. fargesii,* as well as grassland (CK). In each type of plantation, we selected three sample plots in which we investigated stand factors using routine methods. According to the mixed multidot soil collection method, five subplots of 1 m×1 m were selected randomly in each sample plot. We removed the litter from the surface of the soil and then collected soil samples from 0–10 cm and 10–20 cm from the soil profiles. We accomplished those jobs as quickly as possible throughout the entire process. After soil samples were taken from the field to the laboratory, we used a portion of the samples to determine their moisture content quickly and then divided the remaining soil samples into two parts. One part, used to determine chemical properties, was air died, crushed, and sifted three times by sieves with apertures of 2, 1, and 0.25 mm. The other part was quickly sifted with a 1-mm sieve and preserved in the freezer at 4°C. Soil enzyme activity and the number of soil microorganisms had to be measured within one month (Bao, 2000).

3.2 Methods of determination

Our methods of determining basic chemical soil properties included a volumetric method for organic matter, a semimicro Kjeldahl method for total N (TN) and a continuous flowing analyzer for available N (AN). We used Mo-Sb colorimetry to determine total P (TP) and available P (AP), flame photometry for available K (AK), a pH meter to measure pH values (water: soil = 5∶1(w/w)), and conductivity to determine electricity conductivity (EC) (Gan, 1986).

Our methods of determining soil enzyme activity were the Johnson and Temple method to measure the activity of catalase. Our results indicated that we needed $KMnO_4$ at a concentration of 0.1 mol/L, which was used to titrate 1 g of air-dried soil; the results are expressed in units of mL/g. The Hoffman and Seegerer method was used to determine invertase activity, also measured in mL/g. Our results showed the requirements in terms of volume of $Na_2S_2O_3$, used to titrate 1 g of air-dried soil after being cultured for 24 h. The Hoffmann and Teicher method was used to determine urease in mg/g. Again, our result indicated the weight (mg) requirements of NH_4^+-N. The NH_4^+-N was released per gram of air-dried soil after being cultured for 3 h and hydrolyzed by urea (Bao, 2000).

For methods of determining the number of soil microorganism, we chose a beef extract-peptone medium to culture bacteria, Gorodkowa's medium for actinomycetes, and PDA for fungi. We chose a plate dilution method to separate and count strains. The plate culture dishes with the media were placed in an incubator at 28°C. The bacteria were cultured for 2–3 d, and the fungi and actinomycetes were cultured for 3–5 d. Each experimental treatment was replicated three times (Cheng and Xue, 2000).

4 Results and analysis

4.1 Characteristics of soil nutrient distribution in different stand types

Soil nutrients directly affect the growth of forest trees (Yang et al., 2007). There are differences in soil nutrient contents and chemical soil properties because the various forms of forest managements result in different conditions of soil nutrient returns (Liu et al., 2007). Table 1 shows the soil nutrient distribution in four kinds of pure forest plantations, four kinds of mixed plantations, and waste grassland in the Qinling forest region. As can be seen from Table 1, the nutrient contents, such as soil total N, available N, total P, and organic matter, in pure broad-leaved plantations is higher than that in pure coniferous plantations ($p < 0.05$); for conductivity, the opposite applied. Because coniferous stands produce more litter and root exudates and therefore have a greater capability of decomposition and transformation, the amount of nutrient returns will be large. As a result, the amount of soil nutrients in *Q. aliena* var. *acuteserrata* stands is often the largest (Wang et al., 2006). In the four mixed stands (*P. tabulaeformis*×*L. kaempferi*, *P. tabulaeformis*×*Q. aliena* var. *acuteserrata*, *L. kaempferi*×*Q. aliena* var. *acuteserrata*, and *P.tabulaeformis* ×*C. fargesii*), as well as in the nature grassland, the amounts of total N, total P, available P, available K, organic matter, pH, and conductivity in the mixed *L. kaempferi* × *Q. aliena* var. *acuteserrata* forest soils are the largest. The differences in soil nutrients in the other three types of mixed stands were statistically significant at a level of $p < 0.05$. Total N, available N, total P, and organic matter in the *P. tabulaeformis*×*C. fargesii* mixed stands are higher than those in the mixed *P.tabulaeformis*×*L. kaempferi* and *L. kaempferi* ×*Q. aliena* var. *acuteserrata* stands.

The establishment of pure plantations and mixed stands is not a regular feature in this area; however, if we were to create mixed *L. kaempferi*×*Q. aliena* var. *acuteserrata* stands, we could improve these nutrient indices, increase the amount of soil nutrients, and completely change soil acidity and alkalinity.

4.2 Distribution of soil enzyme activity and microorganism in different forest types

There are a variety of complex redox reactions in soil formation processes, as well as conversions and migration of nutrients. In these processes, soil microbes and enzymes play a role that cannot be ignored (Dai and Bai, 1995; Jiao et al., 1997; Wang et al., 2004). As can be seen from Table 2, soil invertase and urease activity improve fundamentally in the mixed stands, compared with pure plantations and nature grassland (i.e., mixed stands improve soil invertase and urease activity). The average value of soil invertase activity increased by 16.7% and the urease activity by 53.8% in the four kinds of mixed plantations, compared with the four pure plantations; in comparison, the soil invertase activity in the nature grassland increased by 9.5% and that of urease by 17.8%, which may be due to high soil nutrient contents. The soil catalase activity declined slightly in the four kinds of mixed plantations, compared with the four pure plantations. Because in the mixed stands, the rate of decomposition of soil denning, lipids, polyphenols, and other harmful substances accelerated, the amount of soil hydrogen peroxide that would have a harmful effect on forest growth was reduced simultaneously (Xu et al., 2000). Soil invertase and urease activity of nature grassland lie basically between that of mixed stands and pure plantations. Given these opposite results of mixed stand plantations of pure plantations, it should be pointed out that nature grasslands receive adequate sunlight and better rainfall and air conditions (Dai and Bai, 1995; Wang et al., 2004), and therefore, soil enzyme activity will be higher than that in plantations and pure forests.

Table 1 Amounts of basic nutrients in different plantations

forest type	soil layer/cm	TN /($g\cdot kg^{-1}$)	AN /($mg\cdot kg^{-1}$)	TP /($g\cdot kg^{-1}$)	AP /($mg\cdot kg^{-1}$)	AK /($mg\cdot kg^{-1}$)	OM /($g\cdot kg^{-1}$)	pH	EC /($dS\cdot m^{-1}$)
P. tabulaeformis	0–10	1.53	35.15	0.66	7.24	261.00	22.20	6.23	0.07
	10–20	1.03	25.64	0.67	8.61	183.00	11.80	5.79	0.04
	mean	1.28e	30.39f	0.67d	7.92a	222b	17.0h	6.01e	0.057b
Q. aliena var. *acuteserrata*	0–10	2.25	46.51	0.86	5.84	179.00	33.10	5.71	0.05
	10–20	1.73	37.61	0.74	2.03	115.00	18.90	5.61	0.04
	mean	1.99b	41.88c	0.80b	3.94c	148f	26.0c	5.66f	0.047c
L. kaempferi	0–10	1.52	36.46	0.69	3.44	172.00	20.50	5.99	0.07
	10–20	1.19	25.84	0.65	2.32	98.00	13.40	6.37	0.04
	mean	1.35de	31.15e	0.67d	2.88d	135g	17.0h	6.18d	0.055b
C. fargesii	0–10	1.97	43.84	0.74	2.78	210.00	29.80	6.21	0.06
	10–20	1.40	27.52	0.66	1.47	104.00	17.60	6.48	0.04
	mean	1.69c	35.68	0.70d	2.12e	157d	23.7d	6.34b	0.049c
L. kaempferi ×*Q. aliena* var. *acuteserrata*	0–10	3.34	51.65	0.87	5.35	267.00	46.20	6.41	0.10
	10–20	2.90	37.60	0.86	2.94	255.00	36.60	6.43	0.09
	mean	3.12a	44.62b	0.86a	4.15b	261a	41.4a	6.42a	0.093a
P. tabulaeformis ×*Q. aliena* var. *acuteserrata*	0–10	1.97	39.90	0.49	1.76	231.00	24.00	6.39	0.07
	10–20	1.00	18.30	0.43	1.66	119.00	12.10	6.16	0.04
	mean	1.49d	29.10	0.46f	1.71f	175c	18.1f	6.27c	0.051c
P. tabulaeformis ×*L. kaempferi*	0–10	1.66	33.77	0.41	2.56	151.00	22.90	6.10	0.06
	10–20	0.93	20.91	0.44	0.92	79.00	11.90	6.36	0.04
	mean	1.29e	27.34	0.42g	1.74f	115h	17.4g	6.23cd	0.051c
P. tabulaeformis ×*C. fargesii*	0–10	2.76	50.70	0.68	2.23	209.00	36.70	5.88	0.06
	10–20	1.63	45.82	0.49	0.48	95.00	18.40	6.49	0.04
	mean	2.20b	48.26	0.59e	1.36g	152e	27.6b	6.18d	0.049c
grassland (CK)	0–10	1.50	32.42	0.76	2.82	180.00	26.20	6.29	0.05
	10–20	1.11	23.25	0.70	1.64	116.00	17.80	6.28	0.03
	mean	1.31e	27.83h	0.73c	2.23e	148f	22.0e	6.28c	0.040d

Note: We used the Duncan method to analyze the data (the replications are the mean nutrient content in the 0–10 and 10–20 cm of soil layers); values in each column with the different letters are significantly different from other forest types at an alpha level of 0. 05.

The statistical results for the soil microorganisms in the eight forest types can be seen in Table 2, where bacteria account for 91.4% to 98.8% of the total number of microorganisms, whereas the fungi account for only 0.051% to 0.26%. In terms of numbers, the order of soil bacteria listed from high to low is pure broad-leaved forest > mixed wood > pure coniferous forest > mixed coniferous and coniferous forest > nature grassland; the order in terms of the number of soil fungi from high to low is pure broad-leaved forest > pure coniferous forest > conifer broad leaved mixed plantations > mixed coniferous and coniferous forest > waste grassland. The number of soil actinomycetes in *L. kaempferi* forest is the highest, four times that in the stand with the lowest number (i.e., the mixed *P.tabulaeformis*×*L. kaempferi* stand). The number of soil microorganisms in mixed stands has increased by 95.9% compared with pure coniferous stands, where the number of bacteria increased by 104.47%. These differences are statistically significant at an alpha level of 0.05 compared with pure coniferous forest. From these results, we conclude that establishing mixed stands will increase the number of soil microorganisms, which might also be beneficial for redistribution of microorganisms. The number of bacteria, fungi, and actinomycetes in the soils of the nature grassland are respectively the lowest compared with pure plantations and mixed stands. As a result, the soil of the eight forest types is conducive to the growth of these three types of soil bacteria and, to some extent, improves the environment for soil microorganisms and accelerates the rate of decomposition and the material cycle.

4.3 Correlation between soil enzyme activity and number of soil microorganism

Most of the enzymes are active substances, released by soil microorganism in the process of metabolism. Therefore, soil enzyme activity depends, to a certain extent, on the number of soil microorganisms (Sun et al., 1997). As can be seen from Table 3, the correlation between the soil-converting enzymes and urease and catalase is highly significant ($p < 0.01$). This shows that there are close ties between these three soil enzymes when they take part in

Table 2 Soil enzyme activity and microorganism in different forest types

forest type	soil layer/cm	invertase /($mL \cdot g^{-1}$)	urease /($mg \cdot g^{-1}$)	catalase /($mL \cdot g^{-1}$)	bacteria /($\times 10^7 \cdot g^{-1}$)	fungi /($\times 10^4 \cdot g^{-1}$)	actinomycetes /($\times 10^5 \cdot g^{-1}$)
P. tabulaeformis	0–10	6.79	6.54	1.15	2.88	3.86	9.04
	10–20	3.17	2.64	1.06	0.74	2.21	5.96
	mean	4.98b	4.59e	1.11bc	1.81e	3.03b	7.50bc
Q. aliena var. *acuteserrata*	0–10	4.82	5.69	1.17	2.34	3.36	17.90
	10–20	2.33	2.69	1.10	1.00	1.92	11.08
	mean	3.57f	4.19f	1.14a	1.67ef	2.64b	15.39a
L. kaempferi	0–10	4.96	6.41	1.14	7.06	19.19	12.75
	10–20	3.38	3.68	1.03	2.46	5.84	6.22
	mean	4.17e	5.05d	1.08d	4.76b	12.51a	9.49b
C. fargesii	0–10	5.49	5.41	1.16	7.79	4.77	9.55
	10–20	2.86	3.70	1.09	3.41	4.94	3.13
	mean	4.17e	4.55e	1.12b	5.60a	4.85b	6.34bc
L. kaempferi × *Q. aliena* var. *acuteserrata*	0–10	6.08	6.73	1.17	4.22	2.07	9.70
	10–20	4.89	5.62	1.07	1.56	1.39	6.95
	mean	5.48a	6.13c	1.12b	2.89d	1.73b	8.33b
P. tabulaeformis × *Q. aliena* var. *acuteserrata*	0–10	5.85	13.50	1.14	5.65	2.27	9.42
	10–20	4.21	4.27	1.06	1.76	1.60	3.92
	mean	5.03b	8.88a	1.10c	3.71c	1.94b	6.67bc
P. tabulaeformis × *L. kaempferi*	0–10	5.35	8.02	1.09	1.84	1.40	5.18
	10–20	3.24	3.97	1.02	0.62	1.06	2.50
	mean	4.30d	6.00c	1.05e	1.23f	1.23b	3.84c
P. tabulaeformis × *C. fargesii*	0–10	6.16	50.70	1.14	5.94	2.71	11.40
	10–20	3.85	45.82	1.09	2.22	1.60	5.76
	mean	5.01b	48.26	1.07e	4.08c	2.16b	8.58b
grassland (CK)	0–10	5.12	32.42	1.10	1.12	1.17	3.83
	10–20	3.89	23.25	1.07	0.09	0.90	2.91
	mean	4.50c	27.83h	1.09d	0.61g	1.04b	3.37

Table 3 Correlation matrix of soil enzyme activity and number of soil microorganisms

index	invertase	urease	catalase	bacteria	fungi	actinomycetes
invertase	1.000	—	—	—	—	—
urease	0.755**	1.000	—	—	—	—
catalase	0.697**	0.478*	1.000	—	—	—
bacteria	0.538*	0.502*	0.670*	1.000	—	—
fungi	0.073	0.016	0.258	0.580*	1.000	—
actinomycetes	0.358	0.278	0.743**	0.465	0.359	1.000

Note: n = 18, $r_{0.05}$ = 0.4683, $r_{0.01}$ = 0. 5897, n is sample size; * correlation is significant ($p<$ 0.05); ** correlation is very significant ($p<$ 0.01). The same comments apply to Table 4.

different biochemical processes at the same time. The correlation between the number of soil microorganisms and the activities of the three soil enzymes are significant or highly significant because a large number of bacteria in the soil contribute considerably to a variety of biological and chemical soil reactions, whereas the level of soil enzyme activity indirectly reflects the amount of products produced in these biochemical reactions. However, the correlation between the activities of the three soil enzymes and fungi is not significant, which may be due to the fact that fungi are insensitive to the impact of natural variation in soils. The correlation between actinomycetes and catalase activity is highly significant ($p<0.01$); this is because both the catalase and actinomycetes reflect the degree of conversion of organic matter simultaneously (Xu et al., 2000; Chen et al., 2002). Of the three important fungi, only bacteria and fungi are correlated with each other significantly ($p<0.05$). This may be related to the special role of soil microorganisms and the level of pH in the soil.

4.4 Correlation between soil enzyme activity, soil microorganisms, and nutrients

By hydrolyzing organic matter, urease generated ammonia and CO_2, the direct sources of nitrogen; their activities indicate the state of soil nitrogen. Invertase resolved high molecular compounds into nutrient substances used by plants and soil microorganisms, and its activity expressed the degree of soil slaking and fertility level. Catalase participated in the transformation process of these substances and the energy in the soil and resolved soil hydrogen peroxide, which is harmful to plants; its activities reflect the intensity of soil biochemistry processes (Jiao et al., 1997; Chen et al., 2002). Bacteria played a very important role in the process of ammonification, whereas fungi played a tremendous role in the process of carbon and energy circulation in the soil. Actinomycetes, relevant to soil humus content, also played a role in soil substance transformation processes, such as the assimilation of inorganic nitrogen and the resolution of carbohydrates, lipids, and tannins, which are difficult to decompose.

As is seen in Table 4, the correlations between the activity of soil invertase, urease, catalase, total N, available N, available K, and organic matter are statistically significant ($p<0.05$) or highly significant ($p<0.01$). These figures show that the activities of the three kinds of soil enzymes improve the quality of soil nutrients. The number of soil bacteria was highly relevant to the content of available N. The correlation between the number of soil actinomycetes, soil available N, and pH value was highly significant ($p<0.01$). The number of soil actinomycetes was also relevant to soil total N and organic matter content and was significant at an alpha level of 0.05. There were positive correlations between the number of soil actinomycetes and other nutritional indices, but these were not statistically significant. That is to say, soil nutrients have a great impact on the distribution and number of actinomycetes. None of the correlation coefficients between the number of actinomycetes and the nutritional indices reached a significant level (i.e., $p>0.05$) from which we can conclude that fungi are not sensitive to soil nutrients. The correlations between soil microorganisms, soil enzyme activity in different forest types, and the content of soil nutrients reached a significant or highly significant level. Therefore, the number of soil microorganisms and

Table 4 Correlations between soil enzyme activity, the number of soil microorganisms, and nutrients

index	total N	AN	total P	AP	AK	OM	pH	EC
invertase	0.5647*	0.5597*	0.1501	0.2931	0.8094**	0.6654**	0.1224	0.7467**
urease	0.5169*	0.5184*	–0.0048	–0.0672	0.5053*	0.5667*	–0.0071	0.4652
catalase	0.6283**	0.8003**	0.4514	0.3544	0.6756**	0.7023**	–0.2231	0.5847*
bacteria	0.4062	0.5600*	0.1202	–0.0198	0.4333	0.4121	0.0242	0.4508
fungi	–0.0822	0.0632	0.1268	0.0917	0.0245	0.0748	–0.1404	0.1382
actinomycetes	0.5226*	0.6860**	0.4860	0.3987	0.4230	0.515*	0.5930**	0.3958

enzyme activity can be used as an important indices of changes in soil fertility.

5 Discussion

Different tree species and forest management modes affect the physical, chemical, and biological soil properties (Chen and Li, 1993; Xu et al., 2000; Jiang et al., 2001; Xue et al., 2003). Soil enzyme activity and microorganisms together promote biochemical processes. Soil nutrients are the source of carbon and nitrogen. However, the kind and number of soil microorganisms determine, to a certain extent, the source of soil enzymes (Xu et al., 2000; Xue et al., 2003; Wang et al., 2006; Liu et al., 2007). Zhu et al. (2007) have analyzed the state of soil nutrients in pure plantations and mixed wood stands in the Qinling Mountains. Their results showed that both plantations and mixed stands had the effect of nutrient enrichment and showed clear differences in their effect on nutrients. We can see from the results of our experiment that there are very great differences in nutrient content, number of soil microorganisms, and soil enzyme activity between the four pure plantations and the four mixed stands. Compared with pure coniferous stands, mixed stands can improve soil nutrients more effectively, especially mixed *L. kaempferi* × *Q. aliena* var. *acuteserrata* stands. In stands of this type, light, water, and nutrients complement each other, improve the efficiency in the use of those elements, and regulate the fertility level of the soil more effectively (Xue et al., 2003). There are differences among certain soil nutrient indices of other mixed forest, and we should analyze their cause further. Compared with the coniferous stands, mixed woods have greater amounts of invertase, urease, and microorganisms. Broad-leaved forests can also maintain these higher levels. Therefore, establishing mixed wood or broad-leaved stands cannot only improve soil fertility and the activity of living creature but can also relieve soil degradation.

We have investigated eight forest types and waste grassland on their correlation between the number of soil microorganisms, enzyme activity, and basic indices of soil nutrients. These three items are closely related. Our study shows the same results as previous investigations. However, the correlation between the number of soil fungi and activities of the three enzymes, as well as the correlation between the number of actinomycetes and all nutrient indices, did not show statistically significant levels. The reasons for this should be investigated further.

6 Conclusions

Restoration of *L. kaempferi* ×*Q. aliena* var. *acuteserrata* mixed plantations can increase soil total N, available N, total P, available P, organic matter, pH, and conductivity and enhance soil fertility fundamentally and significantly. Mixed stands can improve the soil microbial environment effectively, as well as the number of soil microorganisms and their redistribution. There is a close relationship between the number of soil microorganisms, soil enzyme activity, and nutrients. Therefore, the number of soil microorganisms and soil enzyme activity can reflect the changes in soil nutrients in a timely manner.

Acknowledgements This study was supported by the National Natural Science Foundation of China (Grant No. 30471376) and the Program for Talents in Northwest A&F University, China.

References

Bao S D (2000). Soil Agricultural Chemistry. Beijing: China Agricultural Press (in Chinese)

Chen G S, Zhong Z C, Qi D H (2002). Relationship between soil enzymatic activity and fertility of the evergreen broad-leaved forest in the Jinyun Mountain. J Sichuan Teach Coll, 23(1): 19–23 (in Chinese)

Chen J, Li C H (1993). Soil enzyme activity and soil fertility in *Cunninghamia lanceolata* plantation. For Res, 6(3): 321–326 (in Chinese)

Cheng L J, Xue Q H (2000). Microbiology Experiment Technology. Beijing: The World Publish Press Company (in Chinese)

Dai W, Bai H Y (1995). Correlations of soil catalase activity and its kinetic characteristic with some soil properties. J Beijing For Univ, 17 (1): 37–40 (in Chinese)

Gan S Y (1986). Soil Enzyme and Their Research Method. Beijing: Agricultural Press, 260–332 (in Chinese)

Hart S C, Binkley D, Perry D A (1997). Influence of red alder on soil nitrogen transformation in two conifer forests of contrasting productivity. Soil Biol Biochem, 29(7): 1111–1123

Hou B D, Ma F Y, Song Y M, Hou L Y, Cui X D. A study on effect s of different tree species on soil nutrients, enzyme activities and microorganisms. J Jiangxi Agric Univ, 2006, 28(5): 734–738 (in Chinese)

Jha D K, Sharma G D, Mishra R R (1992). Soil microbial population numbers and enzyme activities in relation to altitude and forest degradation. Soil Biol Biochem, 24(8): 761–767

Jiang S N, Zhai M P, Jia L M (2001). Advances on the research of inter-specific nutrient interaction in mixed forest ecosystems. J Beijing For Univ, 23(2): 72–77 (in Chinese)

Jiao R Z, Yang C D, Tu X N, Sheng W T (1997). The change of undergrowth, soil microorganism, enzyme activity and nutrient in different developing stage of the Chinese fir Plantation. For Res, 10 (4): 373–379 (in Chinese)

Liu F D, Jiang Y Z, Wang H T, Kong L G, Wang Y (2005). Effect of continuous cropping on Poplar plantation. J Soil Water Conserv, 19 (2): 102–105 (in Chinese)

Liu Z W, Gao W J, Pan K W, Zhang L P, Du H X, Gao X B (2007). Effect of soil mix-incubation of 4 species artificial forests with litters on the biochemical characteristic. J Northwest A & F Univ, 35(7): 48–54 (in Chinese)

Liu Z W, Li Y S (2003). A study on t he efficiency of nutrient utilization in black locust plantation. Acta Ecol Sin, 23(3): 444–449 (in Chinese)

Prescott C E (1996). Influence of forest floor type on rates of litter decomposition in microcosms. Soil Biol Biochem, 28(10): 1319–1325

Sun C L, Guo Y W, Tong C R, Xu L C, Wang Z (1997). A study on the soil microbes and soil enzyme activities in various Poplar mixed stands. Sci Silv Sin, 33(6): 488–496 (in Chinese)

Sun Z G, Liu J S (2007). Development in study of wetland litter decomposition and its responses to global change. Acta Ecol Sin, 27 (4): 1606–1618 (in Chinese)

Wang Q K, Wang S L, Feng Z W (2006). Comparison of active soil organic carbon pool between Chinese fir plantations and evergreen broadleaved forests. J Beijing For Univ, 28(5): 1–6 (in Chinese)

Wang Y, Wang Q L, Dai L M (2004). Effect of soil moisture gradient on structure of broad-leaved/Korean pine forest in Changbai Mountain. J For Res, 15(2): 119–123 (in Chinese)

Xu J W, Wang W D, Li C (2000). The correlation among soil microorganism, enzyme and soil nutrient in different types of mixed stands of *Pinus thunbergii*. J Beijing For Univ, 22(1): 51–55 (in Chinese)

Xue L, Chen H Y, Kuang L G (2003). Soil nutrients, microorganism and enzyme activities of different stands. Acta Pedolg Sin, 40(2): 280–285 (in Chinese)

Yang T, Xu H, Fang D H, Zhu J J (2007). Soil nutrient, microorganism and enzyme activity in *Pinus sylvestris* var. *mongolica* forests. Chin J Soil Sci, 37(2): 253–257 (in Chinese)

Zhu X Q, Zhang Y W, Wang Y H (2007). The soil nutrient of pure Chinese pine and it mixed with *Quercus acutidentata* forest in Qinling Area. J Liaoning For Sci Technol, 4: 32–33 (in Chinese)