Environ Earth Sci (2011) 62:915–925
DOI 10.1007/s12665-010-0577-4

ORIGINAL ARTICLE

Changes in soil physico-chemical and microbiological properties during natural succession on abandoned farmland in the Loess Plateau

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Received: 29 July 2009 / Accepted: 28 April 2010 / Published online: 19 May 2010

Abstract The re-establishment of natural species-rich heath lands on abandoned farmland is one of the main measures in soil erosion control in the Loess Plateau of China. So, it is important to understand how the vegetation and soil properties develop after land abandonment. The objective of this study was to determine how physico-chemical properties, microbial biomass, and enzyme activities changed for abandoned farmland with an age sequence of 0, 1, 5, 7, 10, 15, 20, 25, 30, 40 and 50 years in Zhifanggou watershed (8.27 km^2), Shaanxi Province, NW China. The results of this study indicate that species succession after land abandonment in the Zhifanggou watershed on the Loess Plateau resulted in a significant improvement in soil chemical and microbiological properties. Soil organic C, total N, available N and K, soil microbial biomass C, N and P, as well as alkaline phosphatase, catalase, saccharase, and cellulase activity increased with time since plantation establishment increased. In contrast, soil bulk density, pH, and polyphenol oxidase activity decreased after farmland abandonment. Urease and α-amylase decreased until 15 years at the early phase of species succession, and then increased. However, there was no significant change in total P and available P during the restoration. Results only implied the tendency that the herbage was developing toward shrub. Although secondary succession plays an important role which improved soil properties after farmland abandonment, the values of these parameters were still much lower than native forest in 50 years. Thus, vegetation recovery after farmland abandonment in a semi-arid environment would be slow and the improvement of soil properties in the Loess Plateau is likely to require a considerably long period of time.

Keywords Loess Plateau · Abandoned farmland · Soil enzyme · Microbial biomass

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Introduction

Overgrazing, intensive cultivation, and the loss of vegetative cover have resulted in the degradation of millions of hectares of cultivated land on the Chinese Loess Plateau. The problem has become extremely serious during the past 50 years. Severe soil erosion has resulted in loss of most of the topsoil in many locations, thus exposing parent material or soils with low nutrient content (Liu and Zhao 1993; Wei et al. 2006; Zhou et al. 2006). The Chinese government acknowledges the severity of this problem and actively promotes comprehensive erosion control through a variety of measures. In an effort to control soil erosion and establish a healthy ecosystem in the Loess Plateau, the government began the "Conversion of Cropland to Forest and Grassland" project at experiment stations in Shaanxi, Sichuan, and Gansu Provinces in 1999. China's policies to foster an environmental-friendly society have drawn widespread attention to soil erosion control and ecological restoration.

Government policies force farmers to abandon fields in parts of the Loess Plateau where erosion losses are especially high. With the enforcement of the projects of agricultural land retrieval to forest and grassland, large area of farmland would be restored to grasslands or forests. Due to the lack of long-term scientific data on historic vegetation changes, it is still unclear whether forests or grasslands were the dominant native vegetation on the Loess Plateau (Zhou 1981; Zhu 1983; Zhang et al. 2000). Zou et al. (2002) considered the vegetation succession sequence on the Loess Plateau was vest land toward herbage, then shrub, and then early stage of forest community of *Populus davidiana* or *Betula platyphylla* and *Platycladus orientalis*, and then changed to forest community such as *Quercus liaotungensis* or *Pinus tabulaeformis*. In last 50 years, *P. orientalis* was developing or developed toward the *Q. liaotungensis*. Moreover, with the stoppage of farming practices, the process of secondary succession begins on the abandoned land. Soil structure gradually recovers as secondary succession proceeds and the ability of the soil to resist erosive forces slowly increases. However, the process and mechanism for vegetative restoration are still unclear. It is important to understand how vegetation and soil properties change in abandoned fields. Furthermore, changes in vegetative patterns may be an indicator of soil quality in arid and semi-arid areas (Kèfi et al. 2007).

The re-establishment of native vegetation in eroded environments has been studied extensively in recent years. Some studies have examined interactions between soil microbial biomass and various soil physical and chemical properties. However, few studies have examined changes in soil enzyme activities in abandoned farmland, especially on the Loess Plateau (Wang et al. 2003; Dai et al. 2007). Such information is required for a better understanding of phytoremediation mechanisms and the interactions between soil and plant communities, and for the appropriate management and conservation of the ecological environment (Tabatabai 1977; Speir et al. 1980; Frankenberger and Dick 1983; Dick et al. 1988a, b). Therefore, the objectives of this study were to (1) evaluate changes in the physico-chemical and microbiological properties of abandoned farmland soil across time on the Loess Plateau and (2) test whether the soil properties would be improved the same as forest or not after 50 years land abandonment, due to the hypothesis proposed in the previous paragraph: herbage would develop toward the early stage of forest or forest community.

Materials and methods

Study area

The study was conducted at the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences. The station is located in the Zhifanggou watershed, Shaanxi Province, NW China (36°46′28″–36°46′42″N, 109°13′03″–109°16′46″E, 1,010–1,431 m altitude, 8.27 km^2) (Fig. 1). The landform and vegetation at the station are typical for the western part of the Loess Plateau. Slopes vary between 0° and 65°. The area has a temperate, semi-arid climate. Mean annual temperature in the watershed ranges from 7.7 to 10.6°C (min. −23.6°C and max. 36.8°C) and the average frost-free period is 157 days. Mean annual precipitation is 505 mm, of which about 70% falls between July and September. The loess-derived soils are fertile but extremely susceptible to erosion. The sand, silt, and clay contents are 65, 24, and 11%, respectively. Soil pH (H_2O) is 5.8.

Experiment design and soil sampling

Ten abandoned farmland sites in the watershed were selected for the study after the history of the sites was determined through interviews with local farmers and village elders and by reviewing rental contracts between farmers and the government. The sites had been abandoned for 1, 5, 7, 10, 15, 20, 25, 30, 40, and 50 years. The following codes will be used to refer to these abandoned fields throughout the rest of the paper: AF1, AF5, AF7, AF10, AF15, AF20, AF25, AF30, AF40 and AF50. The soil was loess-derived. The sites were all located near the top of the loess mounds and there was

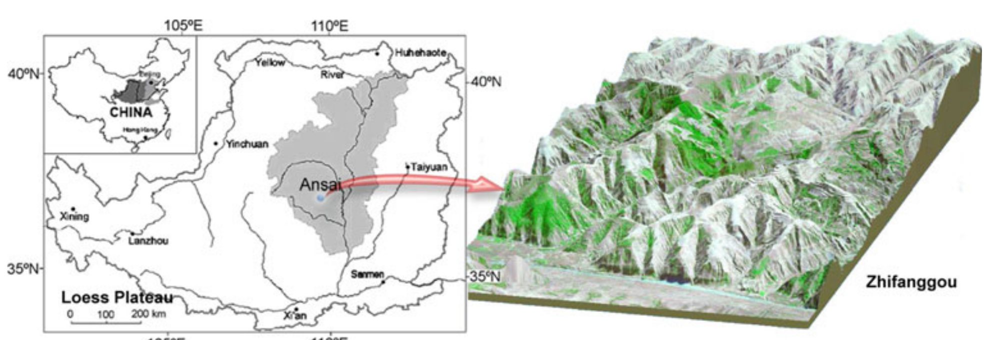

Fig. 1 Location and characteristics of the Zhifanggou catchment

Table 1 Description of the sampling plots

Sites	Age (year)	Landform	Soil type	Altitude (m)	Slope (°)	Vegetation coverage (%)	Primary undergrowth vegetations		
							Vegetation	Coverage (%)	Max/mean height (cm)
AF1	1	HS	LS	1,196	23	38	*Achillea capillaries*, *Heteropappus altaicus*	12, 2.8	76/60, 28/20
AF5	5	HS	LS	1,315	22	42	*Achillea capillaries*	40	104/73
AF7	7	HS	LS	1,315	22	21.5	*Achillea capillaries*, *Heteropappus altaicus*	13.3, 1.4	48/25, 28/20
AF10	10	HS	LS	1,316	23	31	*Achillea capillaries*, *Oxytropis bicolor*	22, 4.1	76/40, 6/5
AF15	15	HS	LS	1,319	24	41	*Achillea capillaries*, *Dracocephalum moldavica*	33.5, 1.8	97/50, 9/7
AF20	20	HS	LS	1,270	28	46	*Artemisia sacrorum*, *Lespedeza dahurica*	7.2, 35	42/40, 47/35
AF25	25	HS	LS	1,284	25	48	*Artemisia sacrorum*, *Stipa bungeana*	16.5, 8.9	49/40, 20/15
AF30	30	HS	LS	1,297	28	64.4	*Artemisia sacrorum*, *Stipa bungeana*	31.4, 7.2	36/20, 19/14
AF40	40	HS	LS	1,286	20	58.6	*Artemisia sacrorum*, *Stipa bungeana*	50, 6.3	72/55, 24/17
AF50	50	HS	LS	1,246	22	83	*Artemisia sacrorum*, *Stipa bungeana*	60, 4.3	80/65, 19/14

CK (0–age) and PO served as control

HS hillside, *LS* loessial soil

little difference among the sites in regard to aspect, gradient, elevation, or previous farming practices. A native forest of *P. orientalis* (PO), which was considered to be the climax community in the region, and a farm field (CK) were selected for comparison. Morphological traits of herbage in each age group are listed in Table 1.

Three 20 m × 20 m plots were established at each site in July 2005. These plots were considered to be true replicates as the distance among them exceeded the spatial dependence (<13.5 m) of most soil chemical and microbial variables (Mariotte et al. 1997). Soil samples were collected from the top 20 cm of each plot with a stainless steel cylinder (5 cm inner diameter). Litter horizons were removed before soil sampling. Ten soil cores were collected in an "S"-type pattern from each plot and then mixed together to make one sample. At the native forest site (PO), samples were collected at a distance of at least 80 cm from the trees. All samples were sieved through a 2 mm screen, and roots and other debris were removed. Half of each sample was kept field-moist in a cooler at 4°C until analyses for soil biological properties could be conducted. The remaining half of each sample was air-dried and stored at room temperature for the determination of soil physical and chemical properties.

Laboratory analysis

Soil bulk density (BD) from 0 to 5 cm was determined using a soil core taken at each sampling point (Institute of Soil Science, Chinese Academy Science (ISSCAS) 1978). Soil chemical analyses were performed on soil samples using standard soil test procedures from the Chinese Ecosystem Research Network (Editorial Committee 1996) and the Soil Science Society of China (1999). Soil organic carbon (OC) was determined by wet digestion with a mixture of potassium dichromate and concentrated sulfuric acid. Total soil nitrogen (TN) was measured by the semi-micro Kjeldahl method, and total soil phosphorus (TP) was determined colorimetrically after wet digestion with $H_2SO_4 + HClO_4$. Available soil nitrogen (AN) was determined with a micro-diffusion technique after alkaline hydrolysis. Available soil phosphorus (AP) was determined by the Olsen method (ISSCAS 1978). Available soil potassium (AK) was measured in 1 mol L^{-1} NH_4OAc extracts by flame photometry. An automatic acid–base titrator (Metrohm 702) was used to determine soil pH in 1:5 soil/water suspensions. Microbial biomass C, N and P (SMBC, SMBN and SMBP) were determined by fumigation extraction method using a k_c factor of 0.38, a k_n factor of 0.54 and a k_p factor of 0.40 (Brookes et al. 1985; Vance et al. 1987; Wu et al. 1990).

We measured the activities of extracellular enzymes using assay techniques modified from Guan (1986). Soil urease (URE, EC 3.5.1.5) activity was measured by indophenol colorimetry with urea as the substrate. The amount of ammonium released over 24 h was assayed colorimetrically at 578 nm and expressed as mg ammonium g^{-1} dry sample. Soil α-amylase (ALA, EC 3.2.1.1) activity was measured with the method of 3,5-dinitro salicylic acid colorimetry using soluble starch as the substrate. The amount of maltose released over 24 h was assayed colorimetrically at 508 nm and expressed as mg maltose g^{-1} dry sample. Soil alkaline phosphatase (ALP, EC 3.1.3.1) activity was measured with disodium phenyl phosphate colorimetry and the amount of phenol released over 24 h was assayed colorimetrically at 660 nm and expressed as mg phenol g^{-1} dry sample. Soil catalase (CAT, EC 1.11.1.6) activity was titrated over 20 min with a standard solution of 0.1 N $KMnO_4$ and expressed as ml 0.1 N $KMnO_4$ g^{-1} dry sample. Soil saccharase (SAC, EC 3.2.1.26) activity was measured with the method of 3,5-dinitro salicylic acid colorimetry using sucrose as the substrate. The amount of 3-amino-5-nitro salicylic acid released over 24 h was assayed colorimetrically at 508 nm and expressed as mg glucose g^{-1} dry sample. Soil polyphenol oxidase (PPO, EC 1.10.3.1) activity was measured with iodine titrimetry method and expressed as ml 0.01 N I_2 g^{-1} dry sample. Soil cellulase (CEL, EC 3.2.1.4) activity was measured with the method of nitro salicylic acid colorimetry. The amount of glucose released over 72 h was assayed colorimetrically at 540 nm and expressed as mg glucose g^{-1} dry sample. All determinations of enzymatic activities were performed in triplicate. The reported values are the averages of the three determinations.

Statistical analysis

All results are reported as mean ± standard deviations. Data were analyzed by one-way analysis of variance (ANOVA) with restoration age as the factor. Student–Newman–Keuls (S–N–K, $\alpha = 0.05$) was used to make multiple comparisons. Curve estimation was used to choose fitting curve types. Changes in soil physical, chemical and microbiological properties were evaluated by linear regression and soil enzyme activities were evaluated by cubic regression. One-way ANOVA was carried out to test the goodness of fit of the regressions. All statistical analyses were performed using SPSS 15 software. Differences at $P < 0.05$ were considered statistically significant. Figures were drawn using Sigma plot 10.0 software.

Results

Soil physico-chemical properties

There was a significant linear decrease with time in soil BD since abandonment increased (Table 2). BD at the AF50 site was 24% less compared to the control (CK) site, but 1.29 times greater than at the native forest (PO) site (Fig. 2a).

There were significant differences in soil organic C, total N, total P, available N, available P, available K, and pH among the sites ($P < 0.01$ or $P < 0.05$, Table 2). Regression analysis showed that organic C, total N, available N, and available K increased linearly with time since abandonment increased. The values of these parameters in the AF50 soil were 1.5–2.7 times greater compared to the farmland (CK) soil, but 19–65% less than in the native forest (PO) soil (Fig. 2b–h). Changes in total soil P and available soil P across time were relatively small and there was no obvious trend. The available P to total P ratio in the AF50 soil was 1.7 times greater compared to the farmland soil (CK), but 14% less than the native forest (PO) soil. Soil pH decreased linearly with time since abandonment increased.

Table 2 The *F* and *P* values from one-way analysis of variance (ANOVA) for soil physico-chemical properties, microbial biomass, and enzyme activities in abandoned farmland of different ages

Index	*F*	*P*
Soil bulk density	13.347	<0.001
Organic C	599.142	<0.001
Total N	3195.132	<0.001
Available N	615.144	<0.001
Total P	28.673	<0.001
Available P	3.605	0.018
Available K	364.151	<0.001
pH	73.646	<0.001
Soil microbial biomass C	1244.819	<0.001
Soil microbial biomass N	76.365	<0.001
Soil microbial biomass P	194.885	<0.001
Urease	26.015	<0.001
Amylase	3.371	0.024
Phosphatases	71.351	<0.001
Catalase	29.277	<0.001
Sucrase	46.377	<0.001
Polyphenol oxidase	111.105	<0.001
Cellulase	81.794	<0.001

Soil microbial biomass

There were significant differences in SMBC, SMBN, and SMBP among the sites ($P < 0.01$, Table 2). Regression analysis showed that SMBC (Fig. 3a), SMBN (Fig. 3b) and SMBP (Fig. 3c) increased linearly with time since abandonment increased. Changes in SMBC, SMBN and SMBP across time were similar to changes in organic C, total N, and available N. Results showed that SMBC, SMBN, and SMBP in the AF50 soil were 1.5–2.7 times greater compared to the farmland (CK) soil, but 49–57% lower compared to the native forest (PO) soil.

Soil enzyme activities

There were significant differences in soil enzyme activities among sites ($P < 0.05$, Table 2). Regression analysis showed a nonlinear correlation between soil enzyme activities and time since abandonment (Fig. 4a–g). Soil URE activity decreased during the first 15 years after abandonment, but then increased till 50 years, and the URE activity in 50 years was 1.4 times greater compared to the

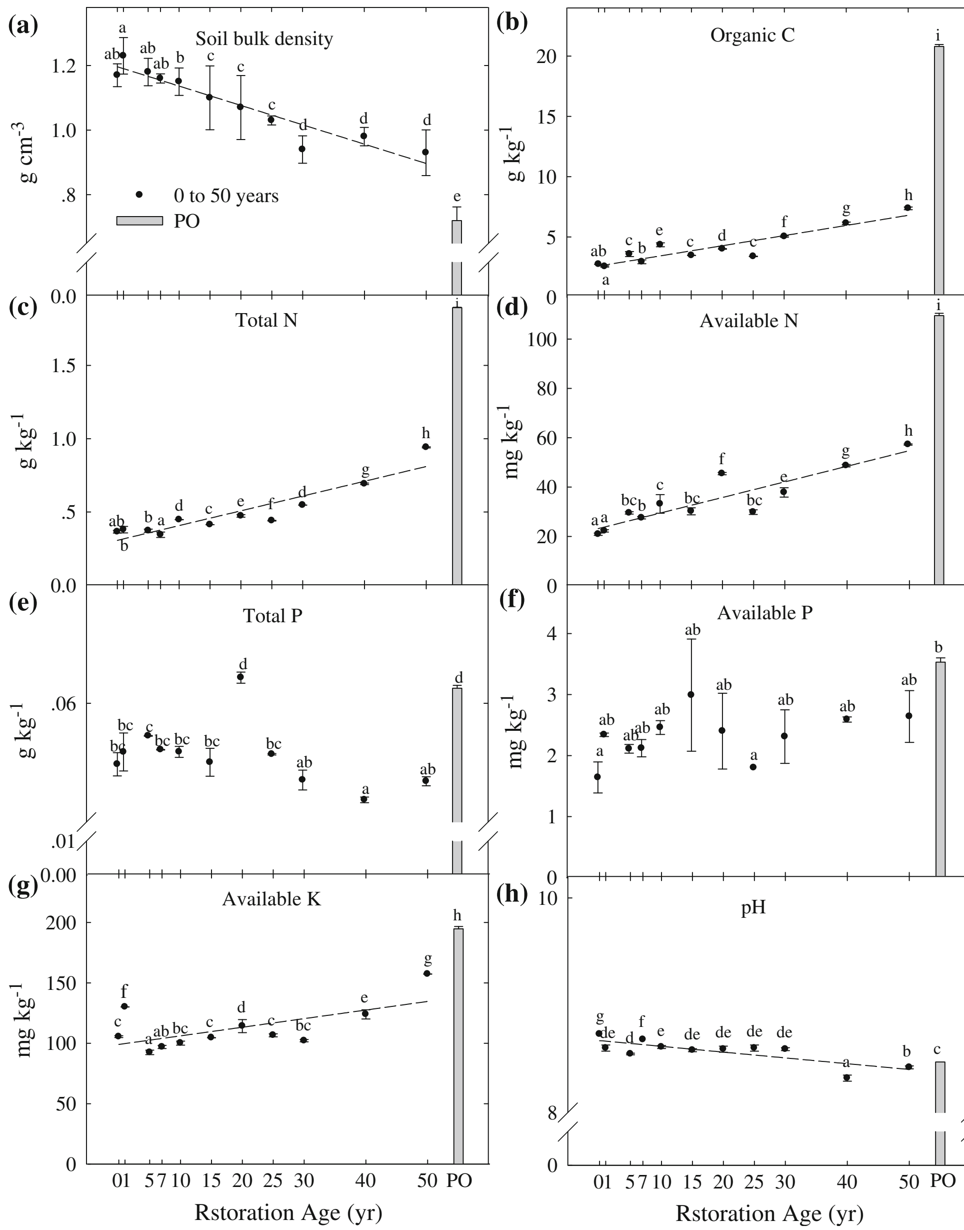

Fig. 2 Changes in soil physico-chemical properties of abandoned farmland across time. *Different letters* indicate significant differences at $P < 0.05$ among restoration ages. The CK (newly abandoned farmland) and PO (climax community of *Platycladus orientalis* L.) served as controls. The results of ANOVA of soil physico-chemical properties in response to age: soil bulk density: $y = 1.196 - 0.006x$, $R = 0.949$, $F_{\text{regression}} = 82.092$, $P < 0.001$; organic C: $y = 2.595 + 0.084$, $R = 0.91$, $F_{\text{regression}} = 48.070$, $P < 0.001$; total N: $y = 0.307 + 0.01x$, $R = 0.921$, $F_{\text{regression}} = 50.483$, $P < 0.001$; available N: $y = 23.173 + 0.629x$, $R = 0.904$, $F_{\text{regression}} = 40.082$, $P < 0.001$; available K: $y = 99.01 + 0.712x$, $R = 0.623$, $F_{\text{regression}} = 5.704$, $P = 0.041$; pH: $y = 8.669 - 0.005x$, $R = 0.781$, $F_{\text{regression}} = 14.036$, $P = 0.005$

farmland (CK) soil, but 52% less than the native forest (PO) soil (Fig. 4a). Soil ALA activity changed in a similar pattern to URE activity, but all its values were lower than the control site. Soil ALA activity in 50 years was still 8% less than in the farmland (CK) soil but higher (almost equal) than the native forest (PO) soil (Fig. 4b). Soil ALP (Fig. 4c), CAT (Fig. 4d), SAC (Fig. 4e) and CEL (Fig. 4g) activities gradually increased with time since abandonment increased. The activities of these enzymes in 50 years were 1.7–4.0 times greater compared to the farmland (CK) soil, but 18–50% less than in the native forest (PO) soil. In contrast to the other soil enzymes, PPO activity decreased with time since abandonment increased (Fig. 4f). Soil PPO activity in 50 years was 39% less than in the farmland (CK) soil, but 1.2 times greater than in the native forest (PO) soil.

Correlation among soil physico-chemical properties, microbial biomass and enzyme activities

Relationships among soil physico-chemical properties, microbiological properties, and soil enzyme activities are shown in Table 3. Soil organic C, total N, available N, available P, available K, SMBC, SMBN, SMBP, URE activity, ALP activity, CAT activity, SAC activity, and CEL activity were positively correlated ($P < 0.01$) with each other but negatively correlated ($P < 0.01$ or $P < 0.05$) with soil BD, PPO activity, and pH. There was a significant ($P < 0.01$) positive correlation among soil BD, PPO activity, and pH. Soil ALA activity was positively correlated with SMBP and URE activity ($P < 0.05$). The correlation coefficients in our study were larger compared

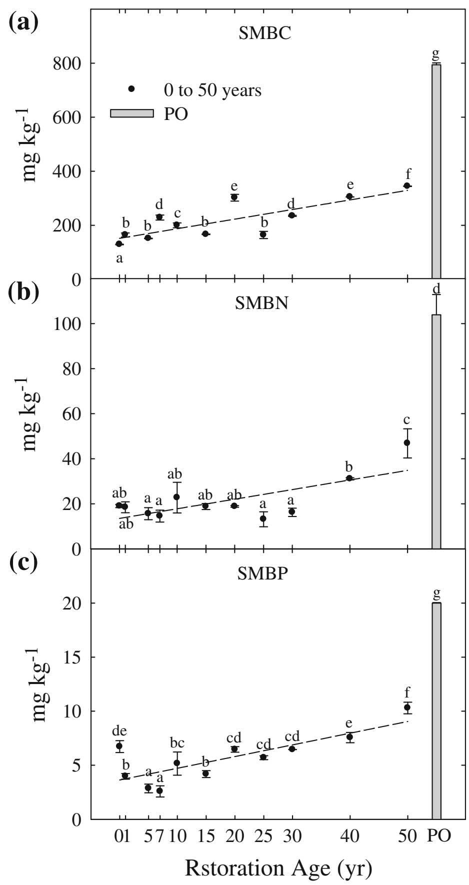

Fig. 3 Changes in SMBC, SMBN and SMBP across time. *Different letters* indicate significant differences at $P < 0.05$ among restoration ages. The CK (newly abandoned farmland) and PO (climax community of *Platycladus orientalis* L.) served as controls. The results of ANOVA of soil physical and chemical properties in response to age: SMBC: $y = 151.946 + 3.553x$, $R = 0.805$, $F_{regression} = 16.619$, $P = 0.003$; SMBN: $y = 13.525 + 0.426x$, $R = 0.718$, $F_{regression} = 9.575$, $P = 0.013$; SMBP: $y = 3.636 + 0.108x$, $R = 0.791$, $F_{regression} = 15.082$, $P = 0.004$

to other studies and may have been affected by the fact that parameter values in the native forest (PO) soil were much larger or much smaller than in abandoned farmland soil. Therefore, a second correlation analysis was conducted in which the effect of the native forest (PO) soil was excluded. According to the results of the second analysis, soil organic C, total N, available N, SMBC, SMBN, SMBP, URE activity, CAT activity, SAC activity, and CEL activity were positively correlated ($P < 0.01$ or $P < 0.05$) with each other but negatively correlated ($P < 0.01$ or $P < 0.05$) with soil BD, PPO activity, and pH (except PPO and URE activities). Total P was only positively correlated with organic C, TN, URE activity, ALA activity, and CEL activity ($P < 0.05$). Available P was only positively correlated with ALP activity, and negatively correlated with pH ($P < 0.05$). Available K was negatively correlated with pH and PPO activity, positively correlated with other indexes (except soil BD, total P, available P, ALA activity, and ALP activity, $P < 0.01$ or $P < 0.05$). ALP was negatively correlated with soil BD, pH and PPO activity, positively correlated with other indexes (except total P, available K, SMBP, and URE activity, $P < 0.01$ or $P < 0.05$). ALA activity was only positively correlated with SMBP and URE activity, negatively correlated with total P ($P < 0.01$ or $P < 0.05$).

Discussion

Soil physico-chemical properties

The restoration of soil fertility by secondary succession is a complicated ecological process which is affected by many biotic and abiotic variables. The classic theory of vegetation succession (Clements 1916) predicts that pioneer plant species modify the initial environment in situ and facilitate replacement by other species. Furthermore, if changes in abiotic environmental factors favor the existing vegetation, the present vegetation may stabilize or even arrest succession, resulting in an alternative stable state (Wilson and Agnew 1992; Adema and Grootjans 2003). Vegetative cover has fundamental effects on soil properties (Rutigliano et al. 2004), mainly due to its contribution of organic matter to soil. Our study showed that soil organic C, total N, available N, and available K generally increased with time since abandonment increased, whereas BD and pH tended to decrease. There was no significant difference in total P (range from 0.055 to 0.062 g kg^{-1}) and available P (range from 1.8 to 3.0 mg kg^{-1}) between the AF1 site to the AF50 site. This may because the total P has a high content in anemogenic sediment (loess soil) on Loess Plateau.

Natural re-vegetation can improve the properties of degraded soil and increase fertility (Campbell et al. 1994). Generally speaking, plant biomass and species diversity increase across time as succession proceeds. Re-vegetated sites results in greater C and N inputs to the soil as plants die and decompose (Cao et al. 2000, 2004). With the plant succession, soil physical and chemical properties will promote compared to the control (CK) soil, probably due to stable species structure (simple to complicated), the increased litter inputs, low incorporation rate of surface litter into soil by soil fauna, reduced rate of soil erosion.

Soil microbial biomass

Our study showed that microbial biomass (SMBC, SMBN and SMBP) was significantly correlated with BD, organic C, total N, available N, available P and available K ($P < 0.01$). These findings agree with many other studies

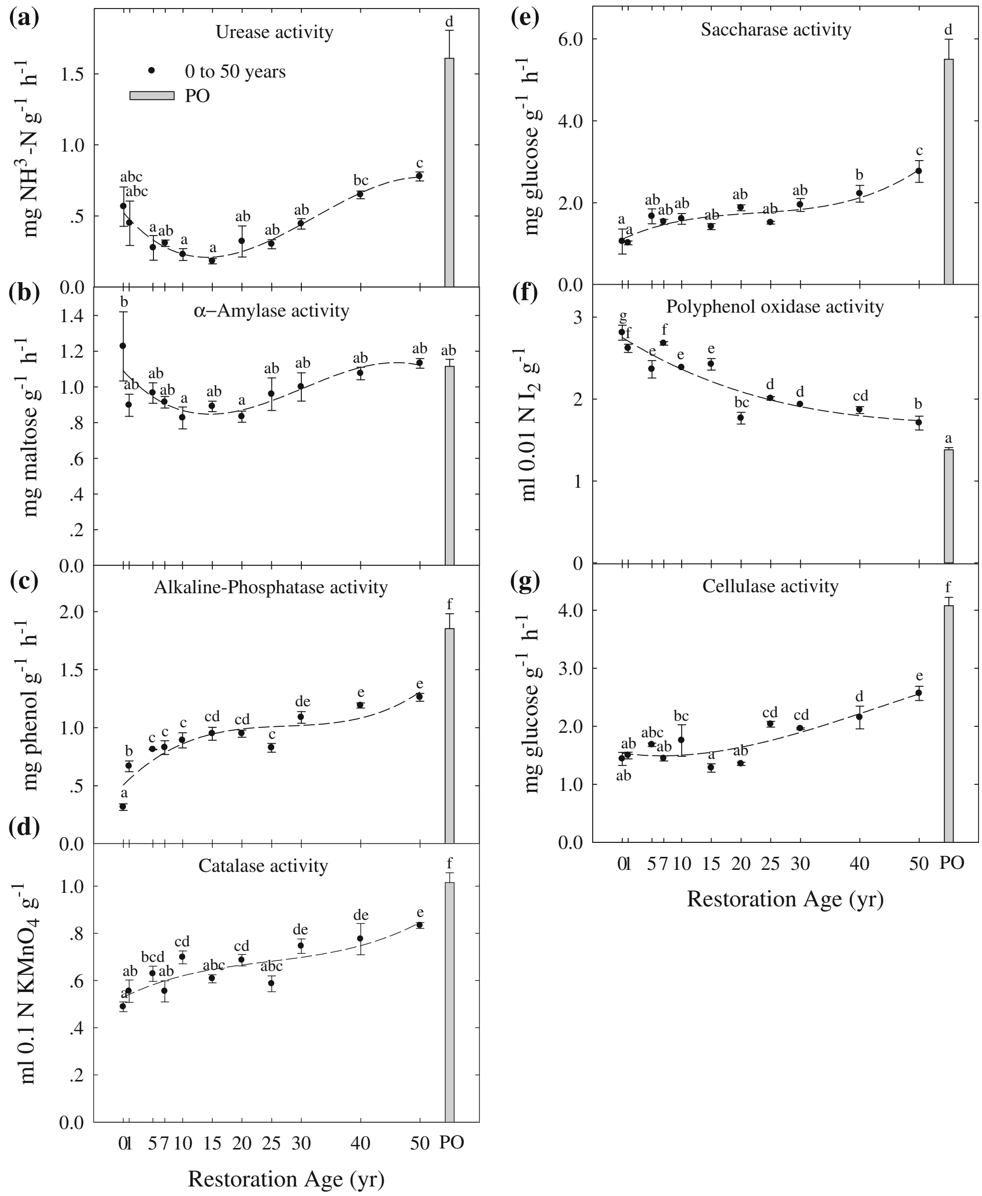

Fig. 4 Changes in soil enzyme activities across time. *Different letters* indicate significant differences at $P < 0.05$ among restoration ages. The CK (newly abandoned farmland) and PO (climax community of *Platycladus orientalis* L.) served as controls. The results of ANOVA of Soil enzyme activities in response to age: urease: $y = 0.521 - 0.049x + 0.002x^2 - 10^{-5} \times 2.335x^3$, $R = 0.9811$, $F_{\mathrm{regression}} = 59.883$, $P < 0.001$; amylase: $y = 1.091 - 0.037x + 0.002x^2 - 10^{-5} \times 1.869x^3$, $R = 0.820$, $F_{\mathrm{regression}} = 4.793$, $P = 0.040$; phosphatase: $y = 0.506 + 0.051x - 0.002x^2 - 10^{-2} \times 2.160x^3$, $R = 0.911$, $F_{\mathrm{regression}} = 11.436$, $P = 0.043$; catalase: $y = 0.529 + 0.012x - 10^{-4} \times 4x^2 - 10^{-6} \times 5.175x^3$, $R = 0.875$, $F_{\mathrm{regression}} = 7.613$, $P = 0.013$; sucrase: $y = 1.107 + 0.067x - 0.003x^2 - 10^{-5} \times 3.811x^3$, $R = 0.941$, $F_{\mathrm{regression}} = 17.989$, $P = 0.001$; polyphenol oxidase: $y = 2.750 - 0.045x + 10^{-4} \times 7x^2 - 10^{-6} \times 3.378x^3$, $R = 0.917$, $F_{\mathrm{regression}} = 12.313$, $P = 0.004$; cellulase: $y = 1.533 - 0.013x + 0.001x^2 - 10^{-6} \times 8.390x^3$, $R = 0.882$, $F_{\mathrm{regression}} = 8.165$, $P = 0.011$

which found significant correlations among soil enzyme activities, microbial biomass, and soil physico-chemical properties. Some researchers have suggested that microbial biomass is a good indicator of changes in soil fertility, since it responds more rapidly and sensitively than chemical nutrition indexes to changes in fertility (Tabatabai 1977; Speir et al. 1980; Frankenberger and Dick 1983; Perucci et al. 1984; Dick et al. 1988a, b; Plaza et al. 2004). For example, short-term measurements of SMBC can reflect long-term trends in total soil carbon (Powlson et al. 1987).

A decrease in soil microbial biomass could result in the mineralization of soil nutrients, whereas an increase in microbial biomass may lead to nutrient immobilization (McGill et al. 1986). Our results indicated that the changes in SMBC across time were similar to our observations for organic C. The increase in SMBC was probably due to an increase carbon input in soil. When carbon was supplied to soil in the form of either roots or residue, the microbial biomass increased in size. We also observed that changes in SMBN and SMBP across time were similar to SMBC possibly due to the microorganism immobilization of nitrogen and phosphorus in the process of the decomposition.

Soil enzyme activities

Considerable evidence suggests that soil enzyme activity can be used as an indicator of soil fertility and microbial activity (Badiane et al. 2001) and to evaluate the influence

Table 3 Correlation coefficients among soil physico-chemical properties, microbial biomass and enzyme activities ($n = 36$)

Index	OC	TN	AN	TP	AP	AK	pH	SMBC	SMBN	SMBP	URE	ALA	ALP	CAT	SAC	PPO	CEL
With PO																	
BD	−.829**	−.854**	−.870**	−.151	−.507*	−.727**	.550**	−.826**	−.781**	−.852**	−.786**	−.316	−.865**	−.852**	−.842**	.867**	−.843**
OC		.989**	.974**	.378	.671**	.874**	−.468*	.975**	.975**	.952**	.919**	.304	.864**	.865**	.973**	−.710**	.947**
TN			.979**	.320	.666**	.923**	−.527**	.971**	.981**	.971**	.941**	.348	.872**	.883**	.976**	−.748**	.959**
AN				.404	.686**	.881**	−.566**	.985**	.950**	.947**	.890**	.263	.915**	.915**	.979**	−.821**	.921**
TP					.211	.273	.216	.452*	.341	.327	.233	−.290	.250	.236	.358	−.290	.211
AP						.614**	−.491*	.684**	.657**	.587**	.582**	−.006	.734**	.645**	.645**	−.508*	.546**
AK							−.543**	.881**	.924**	.909**	.921**	.340	.755**	.787**	.863**	−.670**	.864**
pH								−.481*	−.480*	−.457*	−.475*	−.219	−.681**	−.677**	−.538**	.691**	−.544**
SMBC									.953**	.935**	.905**	.230	.889**	.863**	.964**	−.752**	.901**
SMBN										.950**	.939**	.347	.824**	.826**	.944**	−.658**	.924**
SMBP											.935**	.416*	.785**	.846**	.936**	−.744**	.919**
URE												.478*	.748**	.766**	.869**	−.632**	.901**
ALA													.085	.199	.287	−.150	.382
ALP														.895**	.879**	−.857**	.841**
CAT															.909**	−.877**	.866**
SAC																−.770**	.943**
PPO																	−.742**
Index	OC	TN	AN	TP	Available P	AK	pH	SMBC	SMBN	SMBP	URE	ALA	ALP	CAT	SAC	PPO	CEL
Without PO																	
BD	−.768**	−.748**	−.761**	.330	−.139	−.385	.541**	−.651**	−.477*	−.696**	−.495*	−.219	−.718**	−.721**	−.726**	.813**	−.669**
OC		.959**	.924**	−.424*	.386	.628**	−.806**	.818**	.826**	.776**	.643**	.272	.815**	.905**	.941**	−.775**	.826**
TN			.896**	−.426*	.343	.800**	−.774**	.807**	.889**	.855**	.762**	.339	.737**	.829**	.904**	−.747**	.834**
AN				−.117	.400	.618**	−.773**	.933**	.744**	.748**	.544**	.113	.852**	.881**	.927**	−.879**	.657**
TP					−.140	−.250	.413	−.040	−.389	−.299	−.483*	−.490*	−.212	−.208	−.256	−.020	−.520*
AP						.267	−.437*	.399	.311	.129	.137	−.195	.533*	.384	.304	−.263	.051
AK							−.583**	.617**	.820**	.721**	.783**	.256	.406	.518*	.579**	−.461*	.575**
pH								−.660**	−.676**	−.515*	−.541**	−.168	−.763**	−.737**	−.751**	.682**	−.668**
SMBC									.688**	.652**	.565**	.026	.806**	.760**	.838**	−.768**	.534*
SMBN										.754**	.715**	.357	.535*	.661**	.779**	−.487*	.680**
SMBP											.746**	.455*	.420	.660**	.715**	−.667**	.658**
URE												.587**	.299	.468*	.529*	−.394	.648**
ALA													−.136	.036	.163	−.022	.359
ALP														.811**	.807**	−.813**	.616**
CAT															.870**	−.835**	.702**
SAC																−.779**	.762**
PPO																	−.639**

** $P < 0.01$, *$P < 0.05$ (two-tailed)

of land use on soil properties (Saggar et al. 1999), for its direct expression of the soil community to metabolic requirements and available nutrients, provide a more comprehensive understanding of those key processes linking microbial populations and nutrient dynamics (Sinsabaugh and Moorhead 1994; Schimel and Weintraub 2003), and closely related with microbial biomass because transformations of the important organic elements occur through microorganisms (Frankenberger and Dick 1983). Our results agree with these views which using soil enzyme to evaluation soil quantity is much better than microbial biomass, and indicated that URE, ALP, CAT, SAC, CEL and PPO activities significantly correlated with microbial biomass ($P < 0.01$ or $P < 0.05$, Table 3). At this point, we might suggest that these enzyme indices can be used as a biological indicator of the effectiveness of vegetation and soil restoration.

Soil enzyme assays provide quantitative information on soil chemical processes, nutrient mineralization rates, and organic matter accumulation. At the same time, the activity of soil enzymes is affected by abiotic conditions (e.g., temperature, moisture, soil pH, and oxygen content), the chemical structure of the organic matter, and its location in the soil strata which could influence the growth rate of soil microbes (Zhou et al. 2005). In general, an increase in soil microbial biomass could result in the increase of soil enzyme activities for microorganism that can make better soil moisture condition, soil air condition, temperature, and improve the amount of organic fertilizer (Guan 1986). In our study, enzyme activities were significantly different with restoration age ($P < 0.05$, Table 2). With species succession, the amount of plant litter on the soil surface and the soil organic matter content increased. This resulted in higher URE, ALP, SAC, and CEL activities (Cao and Jiang 2008; Guan 1986). The increase in soil CAT activity in abandoned farmland could affect soil redox conditions and soil solution chemistry. These changes have the potential to dissociate bonds between metals and complexed organic matter and therefore alter soil carbon storage (Jiang et al. 2005). Changes in ALA and PPO activities across time were different than the changes we observed for the other enzymes. ALA activity increased from 15 years after the farmland abandonment and the changes were not correlated with the other parameters in our study. One explanation is that ALA activity was adversely affected by the relatively high soil pH (8.4–8.8) in our study (Guan 1986). Soil PPO activity decreased across time. We suggest that PPO activity in older plantations was inhibited by higher levels of available N (Sinsabaugh et al. 2002).

The low soil enzyme activities indicate low microbial activity which is unfavorable for the decomposition of plant residues on the soil surface, and thus, limited the release of nutrients from the litter. Cao and Jiang (2008) confirmed the generally accepted fact that soil microbial activity is greater in the surface layer than in deeper layers, which attributed to the improved soil environment and the increased organic and inorganic materials released from plants. The greater enzyme activities in surface soil indicated that soil microbiological activity was improved with the increasing age of the plantations; our results found that the soil enzyme activities in surface layer (0–20 cm) were improved with the year of re-vegetation, demonstrating the progressive development of the restoration process.

Changes of soil properties and species with restoration age

With the stoppage of farming practices, the process of species succession begins on the abandoned land. Soil structure gradually recovers as secondary succession proceeds and the ability of the soil to resist erosive forces slowly increases. In our study, the plant community was primarily composed of *Achillea capillaris*, *Heteropappus altaicus* and *Oxytropis bicolor* in the early stage of species succession after farmland abandonment. The dominate species was *A. capillaris*, in which coverage was 12–40%. In the later stage of species succession, *Artemisia sacrorum* and *Stipa bungeana* were the main plant community composition after farmland abandonment, and the dominate species was *A. sacrorum*, in which coverage was 7.2–60% (Table 1). Seedling of shrub was found, such as *Periplocasepium bunge* and *Clematisfruticosa turcz.* However, seedling of forest was not found in our vegetation investigation. So, we might only indicate that the herbage was developing toward shrub.

Lesschen et al. (2008) found that vegetation recovery after land abandonment in a semi-arid environment in the Mediterranean appears to be slow and takes at least 40 years. However, in our study, results only imply the tendency that the herbage was developing toward shrub, and soil chemical properties, microbial biomass, and enzyme activities were still lower than native forest (PO) after farmland abandonment for 50 years. Thus, this recovery rate would be more slowly in Loess Plateau and the improvement of soil properties in the Loess Plateau is likely to require a considerably long period of time.

Conclusion

In arid and semi-arid regions, re-vegetation is important for improving environmental conditions and limiting desertification. The results of this study indicate that species succession after land abandonment in the Zhifanggou watershed on the Loess Plateau resulted in a significant improvement in soil chemical and microbiological properties. Soil organic C, total N, available N and K, soil microbial biomass C, N and P, as well as ALP, CAT, SAC, and CEL activities increased with time since plantation establishment increased. In contrast BD, pH, and PPO activity decreased after farmland abandonment. URE and ALA decreased until 15 years at the early phase of species succession, and then increased. However, there was no significant change in total P and available P during the restoration. Results only implied the tendency that the herbage was developing toward shrub. Although secondary succession plays an important role which improved soil properties after farmland abandonment, the values of these parameters were still much lower than native forest in 50 years. Thus, vegetation recovery after farmland abandonment in a semi-arid environment would be slow and the improvement of soil properties in the Loess Plateau is likely to require a considerably long period of time.

Acknowledgments This work was supported by The State Science and technology Support Project: CAS West Action: Experimental and Demonstration Study on Soil Conservation and Sustainable Ecosystem Rehabilitation on the Loess Plateau (KZCX2-XB2-05), 973 project: Assessment of impact on soil erosion and its indicators (2007CB407205), and the National Sciences Foundation of China Project (No. 40801094). Vegetation Configuration Optimized and Sustained Management Construction Technology on Loess Plateau (2006BAD09B03), The authors thank the members of the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences for technical assistance.

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