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RESEARCH ARTICLE

Effects of Revegetation on Soil Microbial Biomass, Enzyme Activities, and Nutrient Cycling on the Loess Plateau in China

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Abstract

Revegetation is a traditional practice widely used for soil and water conservation on the Loess Plateau in China. However, there has been a lack of reports on soil microbial–biochemical indices required for a comprehensive evaluation of the success of revegetation systems. In this study, we examined the effects of revegetation on major soil nutrients and microbial–biochemical properties in an artificial alfalfa grassland, an enclosed natural grassland, and an artificial shrubland (*Caragana korshinskii*), with an abandoned cropland as control. Results showed that at 0–5, 5–20, and 20–40 cm depths, soil organic carbon, alkaline extractable nitrogen and available potassium were higher in natural grassland and artificial shrubland compared with artificial grassland and abandoned cropland. Soil microbial biomass C (Cmic) and phosphorous (Pmic) substantially decreased with depth at all sites, and in abandoned cropland was significantly lower than those of natural grassland, artificial grassland, and artificial shrubland at the depth of 0–5 cm. Soil microbial biomass N (Nmic) was higher in artificial shrubland and abandoned cropland compared with that in natural and artificial grasslands. Both Cmic and Pmic were significantly different between the 23-year-old and the 13-year-old artificial shrublands at the 0–5 cm depth. The activities of soil invertase, urease, and alkaline phosphatase in natural grassland and artificial shrubland were higher than those in artificial grassland and abandoned cropland. This study demonstrated that the regeneration of both natural grassland and artificial shrubland effectively preserved and enhanced soil microbial biomass and major nutrient cycling, thus is an ecologically beneficial practice for recovery of degraded soils on the Loess Plateau.

Key words: enzyme activity, Loess Plateau, major nutrient, revegetation, soil microbial carbon, soil microbial nitrogen, soil microbial phosphorous.

Introduction

The Loess Plateau (circa 640,000 km^2) is located in the upper- and middle-catchment regions of the Yellow River (Laflen 2000). Local soils have experienced wind- and water-induced detrimental erosion over centuries. Major human activities that influence the Loess Plateau include continuous and widespread stress practices such as overgrazing and large-scale monocultures (Fu et al. 2000). Check dam constructions and other engineering methods were previously considered useful for rehabilitation of local environments, whereas biological approaches such as natural and artificial revegetation have only recently been used for eco-environment rehabilitation (Wang 2002).

Revegetation is an effective and useful soil conservation practice, which can abate soil erosion (Zheng 2006). In disturbed ecosystems, vegetation restoration plays an important role in the ecological integrity of the system (Montalvo et al. 1997). On the Loess Plateau, revegetation is generally achieved by establishing artificial forests or shrubs and natural succession within enclosed area. By the end of 2005, the Grain for Green Program had established approximately 400–600 million of trees in an area of 87,000 km^2 in Shaanxi, China (Zhou et al. 2009). Mummey et al. (2002) indicated that the biomass and growth rate of aboveground vegetation is a distinguishable indicator for evaluating the restoration effect on disturbed ecosystems, whereas Moynahan et al. (2002) and Zhang et al. (2006) suggested that more attention should be paid to the belowground indicators due to the importance of microorganisms in soil organic matter formation and energy transfer. Currently, it is believed that soil microorganisms are essential to long-term ecosystem stability during the practice of vegetative reestablishment.

Due to the involvement in nutrient cycling and organic matter decomposition, soil microbial biomass and enzyme activities (EAs) are the key microbial–biochemical parameters

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used for soil quality monitoring (Bastida et al. 2008). In both natural and agroecosystems, microbial biomass and EAs have often been proposed as the early and sensitive indicators of soil ecological stress or indicators of restoration processes (Doran 1980; Dick & Tabatabai 1993). Typically, 1–5% of the total soil organic matter is composed of microbial biomass. The high turnover rate of microbial biomass results in rapid responses to environmental changes induced by soil management (Gregorich et al. 1997; Breue et al. 2006). As the main source of soil enzymes, microbial populations play a role in controlling soil biogeochemical processes that are critical for nutrient cycling and transformation, and enzyme accumulation outside and inside the proliferating microorganisms contributes to soil EAs (Kiss et al. 1975).

Previous work indicates that microbial biomass carbon (Cmic) and nitrogen (Nmic), as well as several EAs are sensitive indicators of changes in soil organic matter aroused by alterations of land use, cropping system, tillage practices, or soil pollution (Sparling et al. 2003). These microbial indicators are suggested to be helpful for understanding associated changes in soil properties. The plant inputs into soil such as litter, root turnover, and root exudation are key contributors of microbial activity and community structure from both quantitative and qualitative perspectives (Campbell et al. 1997). A study by Hooper et al. (2000) highlighted that plant productivity is associated with soil microbial function through mineralization and immobilization processes driven by root-derived C (rhizodeposition). To better understand these interactions, it is necessary to identify the factors that influence microbial biomasses (Macdonald et al. 2004).

Recently, increasing attention has been focused on the impacts of revegetation on the soil quality of the Loess Plateau in China. Investigations of soil chemical–physical properties on the Loess Plateau showed that soil nutrients and the stability of soil aggregates were improved as time from initial vegetation increased (Zheng 2006; Jiao et al. 2007), whereas a study by Deng et al. (2009) in South China demonstrated that both Cmic and bacterial diversity increased following the 18-year long-term restoration of an eroded forest soil derived from quaternary clay. In our study area on the Loess Plateau, most slope farmlands of potato, millet, and maize were abandoned after the Grain for Green Project was launched in 1999. Currently, alfalfa for animal feed is the most popular artificial grassland. Other common revegetation practices include afforestation with *Caragana korshinskii* and *Hippohae rhamnoides*. It remains unclear how the abandoned cropland ecosystems have recovered since revegetation. Thus, it is necessary to evaluate sensitive soil quality parameters including soil microbial–biochemical indices such as microbial biomass and EAs (Xue et al. 2009).

This study aimed to examine the effects of different revegetation practices on soil nutrient cycling and microbial–biochemical properties on the Loess Plateau. We hypothesized that the revegetation elevated major soil nutrient levels, microbial biomass, and EAs, further improving soil quality. To test this hypothesis, we determined the physical, chemical, and microbial properties (primarily microbial biomass and several EAs) of soils associated with different revegetation practices such as artificial alfalfa grassland, enclosed natural grassland, and artificial *C. korshinskii* shrublands, with an abandoned millet cropland in the adjacent area as control. Results were used to analyze changes in soil nutrient concentrations and EAs in response to specific revegetation practices, further providing insights into the efficiency of relevant soil conservation practices.

Methods

Site Description and Sampling Strategy

This study was conducted in a comprehensively managed long-term field site located at the Guyuan Observatory for Vegetation Protection and Eco-environment (E106°26′–106°30′; N35°59′–36°02′) on the Loess Plateau (Ningxia, China). The site was established in 1982, when several revegetation practices including shrub reconstruction and natural succession by enclosed grassland were carried out for soil and water conservation. In 1999, when the government implemented the policy of "Grain for Green" in western China, local slope farmlands were largely subject to vegetation rehabilitation for prevention of severe soil erosion. Thereafter, land-use changed dramatically in the area. The study site is largely located within the typical hilly region of the Loess Plateau and farmland only accounts for less than 1 of 10 of the total area. The study site has a sub-arid climate with an average annual rainfall of 400 mm (1941–2000). The rainy season lasts from July to September with 24% of the annual rainfall in July. The mean annual temperature is approximately 7°C. Most of

Table 1. Description of four major land uses in the Loess Plateau study area.

Land Use	*Original Vegetation*	*Revegetation Type*	*Note*
Natural grassland	Grazed grassland	Natural grassland	Used for grazing before 1999. It was enclosed because of grain for green project executed.
Artificial grassland	Crop land for potato and millet	Alfalfa	Annually harvested for animal husbandry
Artificial shrubland	Grazed grassland	*Caragana korshinskii*	Dominated by an exotic shrub primarily used for local revegetation, including three ages, e.g. 23-year-old, 13-year-old, and 3-year-old
Abandoned cropland	Millet	—	Adjacent to the revegetated grassland and shrubland

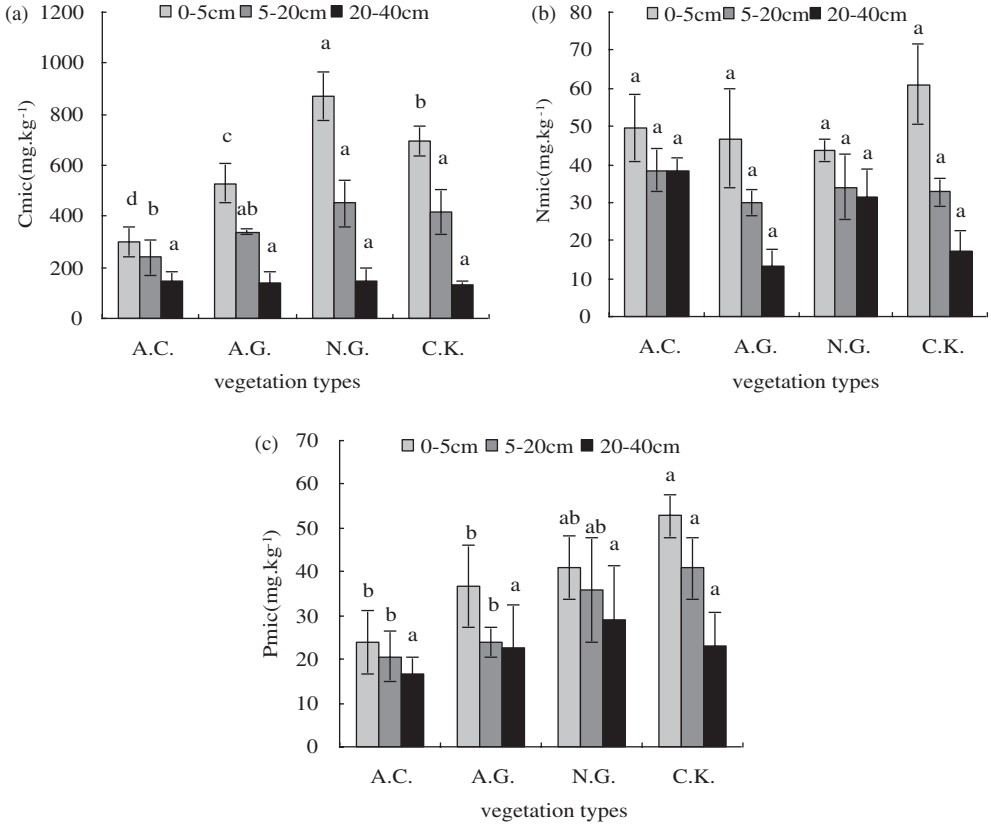

Figure 1. The Cmic (a), Nmic (b), and Pmic (c) of soils with different vegetation types. A.C., abandoned cropland; A.G., artificial grassland; N.G., natural grassland; and C.K., *Caragana korshinskii*. Values are the mean ± SD. Different letters in the same layers in figures indicate significant differences between sites based on LSD ($p < 0.05$).

the regions is between 1,800 and 2,040 m above sea level and is closely dissected by steep or moderately steep gullies.

Four major land uses were selected for study: an artificial grassland, an enclosed natural grassland, artificial *Caragana korshinskii* shrublands, and an abandoned millet cropland as the control (Table 1). *Caragana korshinskii*, the main shrub species used for revegetation in the study area, was planted in three different periods (23-year-old, 13-year-old, and 3-year-old). Thus, samples were respectively collected for these three shrubland treatments, then mixed as a composite soil to compare with other land uses. Individual soils with different shrub ages were also compared to examine the effect of revegetation time on soil quality.

Soil samples were taken from depths of 0–5, 5–20, and 20–40 cm in July 2007. For each land use, three 10 m × 10 m areas were selected and three replicate soil samples were collected in an S shape with five to six sites in each plot using an auger (3 cm i.d.) mixed to form a pooled sample of approximately 1 kg. A total of 36 fresh samples were sealed in plastic bags and a cooling box before being transported to the laboratory for Cmic, Nmic, and Pmic analyses. The water holding capacity was determined by saturating a 100 cm^3 ring cutting sample in water, allowing it to drain to field capacity under cover for 48 hours at room temperature. The moisture content was determined by oven drying at 105°C overnight. All measurements were performed in duplicate. The rest of soil samples were sieved (4 mm) to remove large roots, stones, and macrofauna for nutrient analyses.

Measurement of Soil Microbial Biomass C, N, and P

Soil Cmic, Nmic, and Pmic were determined by the fumigation-extraction method using 15 g oven-dried, field-moist-equivalent soil sample (<2 mm) and 0.5M K_2SO_4 (Brookes et al. 1984, 1985; Vance et al. 1987; Zhou and Li 1998). The Cmic was determined by a TOC Analyzer (Phoenix 8000, Tekmar Dohrmann, Mason, OH, U.S.A.), and Nmic determined colorimetrically with a spectrophotometer (Hitachi, Tokyo, Japan, UV2300) at 220 and 275 nm. The Cmic and Nmic were calculated using a k_{EC} factor of 0.45 (Wu et al. 1990) and a k_{EN} factor of 0.54 (Vance et al. 1987), respectively. Soil Pmic was determined colorimetrically with a spectrophotometer. Briefly, 2.5 g of fumigated and non-fumigated soil were put into 150-mL flask containing 50 mL of 0.5 mol/L $NaHCO_3$ solution with 2 g P-free active charcoal; 5 mL of Mo–Sb spetrochrometry solution was then added for color development. After 30 min, the color was determined with a spectrophotometer (Hitachi, UV2300) at 700 nm. The Pmic was calculated using the k_{EP} factor of 0.40 (Hedley & Stewart 1982).

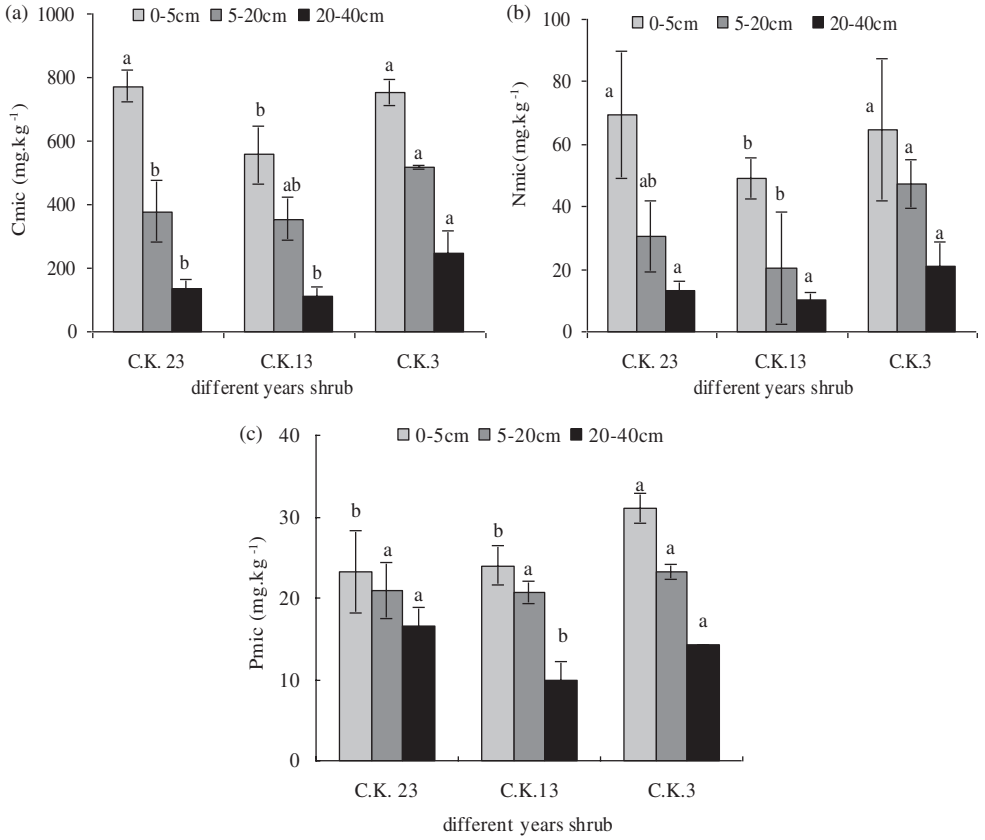

Figure 2. The Cmic (a), Nmic (b), and Pmic (c) of soils vegetated with *Caragana korshinskii* of different ages. C.K.23: 23 years old; C.K.13: 13 years old; and C.K.3: 3 years old. The values are the mean ± SD. Different letters in the same layers in figures indicate significant differences between groups based on LSD ($p < 0.05$).

Analysis of Soil Enzyme Activities

In this study, invertase and urease activities were selected to indicate soil C and N turnover, and alkaline phosphatase activity selected to indicate soil P turnover. Because the samples were calcareous soil, catalase activity was employed as the indicator of oxidative stress response. The EAs were assayed according to Guan et al. (1991) and An et al. (2009).

For determination of urease activity, 5 g of air-dried soil (<1 mm) was incubated in 5 mL of citrate solution (pH 6.7) and 5 mL of 10% urea solution at 37°C for 3 hours. The soil solution was diluted to 50 mL with distilled water and the suspension was filtered with 1 mL aliquot treated with 4 mL of sodium phenol solution (mixture of 100 mL 6.6M phenol solution and 100 mL 6.8M NaOH) and 3 mL of 0.9% sodium hypochlorite. The released ammonium was quantified colorimetrically with a spectrophotometer (Hitachi, UV2300) at 578 nm.

For determination of alkaline phosphatase activity, 10 g of air-dried soil (<1 mm) and 2 mL of toluene were incubated in 10 mL of disodium phenyl phosphate and 10 mL of 0.05M borate buffer (pH 9.6) at 37°C for 3 hours. The samples were filtered, and the filtrate was colored with 0.5 mL of 2% 4-Aminoantipyrine and 8% potassium ferrocyanide and the released phenol was determined colorimetrically with a spectrophotometer (Hitachi, UV2300) at 510 nm (Guan et al. 1991).

Catalase activity was determined according to Cohen et al. (1970). Briefly, decomposed hydrogen peroxide was measured by reacting with excessive potassium tetraoxomanganate (VII), $KMnO_4$. The residual $KMnO_4$ was measured spectrophotometrically at 480 nm.

Analysis of Soil Nutrients

Soil samples were air-dried and passed through a 2-mm sieve. Major soil chemical properties were analyzed according to ISSCAS (1981). Soil OC was determined by wet digestion in a mixture of 5 mL 0.136 mol/L potassium dichromate and 5 mL concentrated sulfuric acid, and total N measured by the semi-macro Kjeldahal method. Alkali-Extr-N was measured using a micro-diffusion method, in which NH_3 was released from the soil sample by NaOH and then absorbed by boric acid. The ammonium borate product was titrated with 0.01M HCl. Available phosphorus (Av-P) was extracted and measured in a buffered alkaline solution with 0.5M sodium bicarbonate. The extracts were quantified calorimetrically with a spectrophotometer (Hitachi, UV2300) at 660 nm. Av-K was extracted by 1 mol/L NH_4OAc and measured with flame photometry.

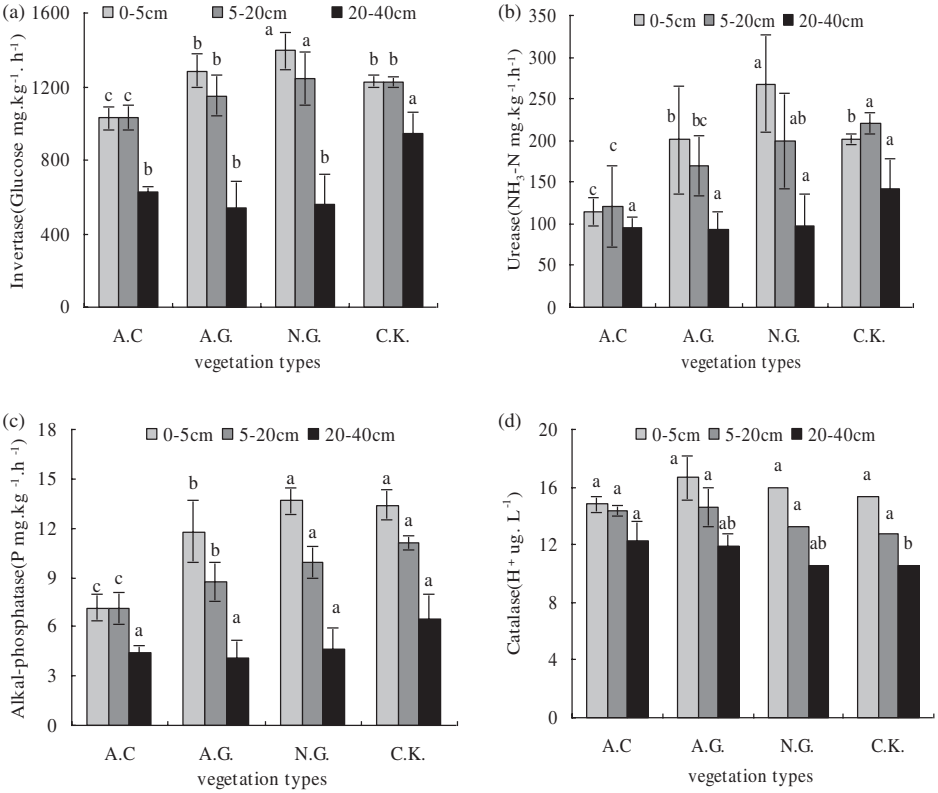

Figure 3. The activities of invertase (a), urease (b), alkaline phosphatase (c), and catalase (d) in soils with different vegetation types. A.C., abandoned cropland; A.G., artificial grassland; N.G., natural grassland; and C.K., *Caragana korshinskii*. The values are the mean ± standard deviation. Different letters in the same layers in figures indicate significant differences between sites based on LSD ($p < 0.05$).

Statistical Analysis

Excel 5.0 and SPSS 11.0 were used for statistical analysis. A graphic check of the postulates was performed based on the residue distribution. One-way analysis of variance (ANOVA) following by Fisher's least significant difference (LSD) test ($p < 0.05$) was used to compare the revegetation effects at depths of 0–5, 5–20, or 20–40 cm, respectively.

Results

Distribution of Soil Microbial Biomass C, N, and P

Soil Cmic content significantly varied among the artificial grassland, enclosed natural grassland, *Caragana korshinskii* shrublands, and abandoned cropland at 0–5 cm ($p < 0.05$, $n = 3$), but not at 10–20 cm (Fig. 1). Soil Pmic concentration showed a similar trend at different soil depths, but the variations were not as significant as those of Cmic. In contrast, Nmic distribution with soil depths was different from Cmic and Pmic. The Nmic content was higher in *C. korshinskii* shrublands, and Pmic content was lowest in enclosed natural grassland.

The soil microbial biomass was related to the age of established shrublands (Fig. 2a–c). Among the three age groups, Cmic and Nmic both decreased with soil depth. At 0–5 cm, significant differences were found between the Cmic contents of the 23-year-old and 13-year-old shrublands ($p < 0.05$, $n = 3$), but not associated Nmic contents. The Pmic content was highest in the 3-year-old shrubland and significantly different from that of the 23-year-old and 13-year-old shrublands. The Pmic content slightly decreased with soil depth, similar to the Cmic and Nmic distribution.

Variations in soil Enzyme Activities

The activities of soil invertase, urease, and alkaline phosphatase were generally higher in enclosed natural grassland and *C. korshinskii* shrublands than those in artificial grassland and abandoned cropland (Fig. 3a–c). However, significant difference in soil invertase activity among these sites was not as much as those of other soil EAs. The highest level of invertase activity was 1,537.6 $mgGkg^{-1}\,h^{-1}$ in enclosed natural grassland, and the lowest was 1,097.5 $mgGkg^{-1}\,h^{-1}$ in abandoned cropland. Urease activity varied significantly among the four land uses, with the highest level (293.77 $mgNH_3\text{-}Nkg^{-1}\,h^{-1}$) in enclosed natural grassland, and the lowest level (132.68 mg $NH_3\text{-}Nkg^{-1}\,h^{-1}$) in abandoned cropland at the same depth. The urease activity in enclosed natural grassland was approximately 2.5 times higher than that in abandoned cropland. There were no significant differences in urease activity at 20–40 cm among the four land uses.

Compared to other EAs, catalase activity showed a different variation trend (Fig. 1d). There were no significant differences in catalase activity at the depth of 0–5 and 5–20 cm among all land uses.

Soil Nutrients Associated with Different Revegetation Practices

There were substantial differences in selected major soil chemical properties among the four land uses (Table 1). Soil OC, Alkali-Extr-N, and Av-K were higher in enclosed natural grassland and *C. korshinskii* shrublands than those in artificial grassland and abandoned cropland at 0–5, 5–20, and 20–40 cm depths. The highest OC (15.56 g/kg) and TN levels (1.37 g/kg) were found in fenced natural grassland, whereas the highest Alkali-Extr-N (116.06 mg/kg) and Av-K (142.41 mg/kg) were found in *C. korshinskii* shrublands. In contrast, Av-P level was higher at the 0–5 cm depth in abandoned cropland than those in the other three revegetated sites. Generally, soil nutrient levels were higher at 0–5 cm than at 5–10 and 10–20 cm.

Relationships Among Soil Microbial and Biochemical Parameters

Significant correlations were found among soil microbial and biochemical parameters determined in this study (Table 2). For example, soil OC, Alkali-Extr-N, TN, and Av-K were positively correlated with soil EAs. Positive correlations were also found among Cmic, Nmic, and Pmic ($R = 0.39–0.52$, $p < 0.001$, $n = 63$) and between invertase activity and Nmic ($R = 0.27$, $p < 0.05$, $n = 63$). Among the soil enzymes, urease activity was significantly correlated with invertase and alkaline phosphatase activities ($R = 0.84–0.87$, $p < 0.01$, $n = 63$), alkaline phosphatase activity positively correlated with invertase activity ($R = 0.27$, $p < 0.05$, $n = 63$), and catalase activity significantly correlated with other EAs ($R = 0.46–0.72$, $p < 0.01$, $n = 63$) (Table 3).

Discussion

Grasses, shrubs, and meadows have been used for land rehabilitation and revegetation on the Loess Plateau for many years. However, there is a lack of evaluation of the sensitive soil quality parameters, which could differentiate the recovery systems based on labile nutrient transformation and cycling status. A number of studies have focused on the potential of microbial biomass and EAs as indices of soil productivity or as indicators of microbial activity in different systems (Dick et al. 1996; Acosta-Martínez et al. 2007; Bastida et al. 2008). In this study, we used Cmic, Nmic, Pmic, and selected EAs as indicators of nutrient cycling. Results showed that associated soil parameters were affected by different revegetation practices. Both soil OC and Cmic were higher in the artificial shrublands and fenced natural grassland, reflecting the positive impacts of revegetation on soil organic C pools after the ending of cropping- and grazing-induced ecological pressure, and the positive impact

Table 2. Major nutrient levels of soils with different types of revegetation (mean ± SD).

	O.C (g/kg)			*Av-N (mg/kg)*			*Total N (g/kg)*			*Av-K (mg/kg)*			*Av-P (mg/kg)*		
Vegetation Types	*0–5 cm*	*5–20 cm*	*20–40 cm*	*0–5 cm*	*5–20 cm*	*20–40 cm*	*0–5 cm*	*5–20 cm*	*20–40 cm*	*0–5 cm*	*5–20 cm*	*20–40 cm*	*0–5 cm*	*5–20 cm*	*20–40 cm*
Abandoned cropland	10.01 ± 1.27 b	9.72 ± 0.90 b	7.37 ± 2.27 a	65.33 ± 2.26 b	61.36 ± 1.68 b	45.75 ± 3.62 a	0.52 ± 0.26 a	0.35 ± 0.07 ac	0.32 ± 0.03 a	88.47 ± 11.92 b	90.95 ± 34.24 a	46.96 ± 0.72a	15.11 ± 4.79 a	11.97 ± 3.04 a	7.71 ± 1.29 a
Artificial grassland	13.07 ± 7.29 ab	10.04 ± 2.17 b	6.47 ± 1.88 a	88.55 ± 19.53 ab	69.20 ± 13.22 ab	44.28 ± 11.51 a	1.23 ± 0.36 a	1.04 ± 0.33 a	0.71 ± 0.24 a	118.03 ± 25.12 a	66.40 ± 14.95 a	43.76 ± 8.27a	12.21 ± 1.98 a	9.00 ± 0.52 b	7.54 ± 1.09 a
Natural grassland	16.86 ± 4.78 a	11.53 ± 3.70 ab	7.30 ± 3.79 a	103.62 ± 26.35 a	76.68 ± 17.36 ab	48.33 ± 20.23 a	1.37 ± 0.62 a	1.01 ± 0.47 ab	0.65 ± 0.29 a	125.60 ± 17.74 a	71.88 ± 21.96 a	42.67 ± 9.92 a	11.08 ± 2.03 a	9.00 ± 1.46 b	8.00 ± 1.34 a
Artificial shrubland (*Caragana korshinskii*)	15.56 ± 2.21 a	13.26 ± 1.84 a	8.05 ± 5.46 a	116.06 ± 16.23 a	87.46 ± 6.54 a	54.87 ± 21.78 a	0.89 ± 0.63 a	0.71 ± 0.46 abc	0.54 ± 0.32 a	142.41 ± 6.91a	63.80 ± 6.34 a	40.03 ± 7.08 a	12.51 ± 6.66a	7.51 ± 1.62 b	5.38 ± 1.62 b

Different letters within the same column indicate significant differences between sites based on LSD ($p < 0.05$).

Table 3. Correlation coefficient (R) among major soil nutrient levels and soil microbial parameters.

R	*Cmic*	*Nmic*	*Pmic*	*Invertase*	*Alkaline phosphatase*	*Urease*	*Catalase*	*O.C*	*Alkali-Extr. N*	*T. N*	*Av-K*	*Av-P*
Cmic	1	0.52**	0.39**	0.09	0.11	0.24	0.13	0.15	0.09	0.22	0.08	0.01
Nmic		1	0.22	0.27*	0.27*	0.25*	0.24	0.24	0.26*	0.17	0.39**	0.31*
Pmic			1	−0.03	−0.01	−0.01	0.24	−0.06	−0.07	−0.12	0.08	0.07
Invertase					0.92**	0.84**	0.69**	0.81**	0.78**	0.43**	0.74**	0.34**
Alkaline phosphatase					1	0.87**	0.72**	0.89**	0.86**	0.45**	0.83**	0.38**
Urease						1	0.46**	0.85**	0.83**	0.37**	0.69**	0.19
Catalase							1	0.60**	0.51**	0.43**	0.72**	0.52**
O.C								1	0.93**	0.28*	0.84**	0.37**
Alkali-Extr. N									1	0.26*	0.83**	0.38**
T. N										1	0.37**	0.17
Av-K											1	0.51**
Av-P												1

Stars (*) indicate differences between soil parameters based on t test (*$p < 0.05$; **$p < 0.01$).

of substantial plant biomass increase potentially resulted from the accumulation of leaves carbons and abundant root exudates. Cmic, Pmic and invertase, urease are more sensitive than soil nutrients to affect revegetation and so they can be used as indicators of the effectiveness of revegetation.

Av-P and Nmic levels were influenced by fertilization during the ploughing season. The Nmic level was found to be higher in abandoned cropland than in fenced natural grassland and artificial grassland, but lower than that in *Caragana korshinskii* shrublands. This was similar to a previous finding in another area on the Loess Plateau, where composite fertilizers including N, P, and K were applied (Xue et al. 2009). Due to the volatilization and utilization by crops, residual N and P fertilizer remained in the surface soil layer, whereas little C was left in the soil. Thus, N and P were initially higher in the abandoned cropland than in [where?].

Artificial *C. korshinski* vegetation has been shown to provide significant protection against water-induced soil erosion in areas afforested with leguminous plants (Su & Zhao 2003). However, little is known regarding local soil quality changes after shrub control practices were implemented to reduce water-induced soil erosion on the Loess Plateau (Jiao et al. 2007). The results in this study are consistent with our previous findings that the levels of Cmic and Nmic were positively correlated with those of soil nutrients, organic matter, and soil EAs in the years following natural revegetation (An et al. 2009). Shrub establishment and growth are important safeguards against soil erosion, and the fallen leaves of shrubs can also enrich soil nutrients (Wezel et al. 2000). Carbon fixation via photosynthesis and the subsequent transfer of C to soil via leaf litter and root turnover contribute to soil C accumulation (Leifeld & Kögel-Knabner 2005). Soil N fixation by *C. korshinski* and subsequent N release by litter decomposition could increase the soil N content (Su & Zhao 2003). Together, these differences could lead to variations in Cmic, Nmic, and Pmic after the establishment of shrublands. In our previous studies at the same sites (An & Huang 2003), soil nutrients such as organic C and available N were found lower in 13-year-old *C. korshinski* shrubland. Lower soil enzyme and microbial activities resulted from the lower level of relevant substrates. A related plant investigation showed that the mean height, shrub shoots, and crown diameter of 23-year-old *C. korshinski* stands were higher than that of the 13-year-old shrubs (An et al. 2010). The greater biomass meant that more leaves return to the soil and root products excrete more nutrients and EAs should be affected by them. Other reasons for the lower values in soil parameters at the 13-year-old *C. korshinski* shrubland could be attributed to the spatial variability of soil. Despite that the soil variability could be a disadvantage and limitation for assessment of "space" versus "time," the current method is still effective to investigate the changes in soil quality over time after revegetation (Sparling et al. 2003; Li et al. 2007).

Implications for Practice

- Revegetation of enclosed natural grassland and artificial *Caragana korshinskii* shrublands improved the major soil nutrient levels and EAs and are effective vegetation for restoration of degraded soils on the Loess Plateau in China.
- Planting of pioneer species in degraded or eroded soil enhances the soil micro-scale environment. For example, the exotic *C. korshinski*, an easy-surviving and drought-enduring plant, is particularly practical for regeneration of degraded soils.
- The fenced grassland rehabilitation by natural succession can be used for land degradation mitigation in arid and semiarid land area. It can preserve and enhance soil nutrients and soil EAs.

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