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Distribution of soil organic C, N and P in three adjacent land use patterns in the northern Loess Plateau, China

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Abstract The northern Loess Plateau is an important cropping-pastoral ecotone and wind–water erosion crisscross region in China, but the distribution of soil organic carbon (C), nitrogen (N) and phosphorus (P) in different land uses across this vulnerable ecoregion is not well understood. This study was carried out to determine the distribution patterns of soil organic C, N and P in native grassland and in two woody lands (Chinese Pine land and Korshinsk Peashrub land) that were established on the native grassland 28 years ago. In the north part of the Loess Plateau, the concentrations of soil organic C, N and P were lower than in the southern Loess Plateau either across or within the land use patterns. The concentrations and stocks of organic C and total N were significantly decreased in Chinese Pine and Korshinsk Peashrub lands compared with those in native grassland in the surface 0–40 cm soil layer, where more than 70% of the roots were distributed. The decreases in organic C in 0–40 cm soil layers were 2.6 and 3.0 Mg C ha^{-1} (26.3 and 27.7%) by Chinese Pine and Korshrinsk Peashrub, while those of total N were 0.6 and 0.4 Mg N ha^{-1} (31.5 and 17.2%), respectively, compared with native grassland. Both concentration and stock of total P varied only slightly with land use. The findings suggested that the conversion of natural grass into Chinese Pine and Korshinsk Peashrub resulted in decreased soil organic C and total N in the surface 0 to 40 cm soil layer of the northern Loess Plateau. Our results further indicated that a combination of low temperatures, little precipitation and large soil degradation impede increasing C and N stocks by afforestation, and the afforestation on grassland should be viewed very critically in such areas.

Keywords Chinese Pine · Korshinsk Peashrub · Native grass · Nitrogen · Phosphorous · Organic carbon · The northern Loess Plateau

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Introduction

Land use change has received intensive interest because of its potential influences on global carbon cycling, soil quality, land management and regional social economic development (Rudel et al. 2005;

Richards et al. 2007). As a major land use change form, grassland afforestation with various tree species has occurred in many parts of the world, including China, New Zealand, Australia, USA, Canada and some African and European countries. This is due to an increasing demand for timber and wood products and expected high economic returns from forestry, the desire to reduce soil erosion and conserve soil, or the potential for forests to sequester carbon to counter climate change (Farley and Kelly 2004; Rudel et al. 2005; Qiu 2007; Xue et al. 2007; MfE 2008). Grassland afforestation is likely to affect the C cycle and the amount of C stored in soil (Jackson et al. 2002; Farley et al. 2004; Davis et al. 2007). Soil nutrient cycling can also be altered by grassland afforestation (Neill et al. 1999), and interactions between C and nutrient cycles may influence soil C storage and regulate nutrient availability (Conant et al. 2001). This land use-induced gradient in soil C and nutrient availability will in turn influence biomass production and ecosystem function, emissions of pollutants such as nitrogen, acidifying substances and greenhouse gases (Foster et al. 2003). For example, large areas of pasture have been converted to plantation forests throughout New Zealand, and these new forests represent a major C sink for New Zealand, offsetting about 59% of the greenhouse gas (CO_2-equivalent) emissions from energy and industrial uses and 29% of the total emission in 2006 (MfE 2008). Therefore, understanding the effects of grassland afforestation on soil properties may have important implications for sustainable management of land resources and associated ecosystem processes (Fahey and Jackson 1997). Although the effects of some land use changes on soils have been studied at different time scales from a few years after the change (O'Connell et al. 2003) to several centuries (Verheyen et al. 1999) or even millennia (Dupouey et al. 2002), grassland afforestation induced changes in C, N and P status vary greatly with location, and the specifics of land use change can depend upon political, social, economic and environmental conditions (Rudel et al. 2005). Therefore, the changes in soil C, N and P conditions in different regions resulting from grassland afforestation should be further studied.

The north part of the Loess Plateau is the center of the cropping-pastoral ecotone and wind–water erosion crisscross region in China. This area is the ecotone of the traditional agricultural region and pastoral region and suffers intensive and extensive soil erosion. Water erosion occurs during the rainy season, while wind erosion occurs during strong windy days (mainly in Spring and Autumn), which causes serious soil and water losses and makes the region a main source of coarse sediments to the Yellow River's middle-lower reaches (Tang 2004). Since the 1990s, research in the region has focused on spatial and temporal distributions of soil water (Hu et al. 2008), soil water carrying capacity for vegetation (Xia and Shao 2008), water transport at the interface of soil, vegetation and the atmosphere and cycles in ecosystems and watersheds (Fan et al. 2007) and other hydrologic aspects. However, the status of organic C and nutrients as well as land use impacts are not well understood. This information is important to enhance the understanding of global change and regional ecosystem management.

Due to the special characteristics in climate and land surface processes, we hypothesize that in the northern Loess Plateau (1) soil organic C and nutrient conditions are significantly affected by land use change and (2) soil organic C, total N and the effects of land use on them are strongly different from those in the southern Loess Plateau. We conducted this study to evaluate the status of soil C and nutrients in the region and their relations with land use patterns so as to test our hypothesis and provide implications for land management in the region.

Materials and methods

Study site

This study was conducted at the Shenmu Erosion and Environment Research Station of the Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, in the Liudaogou small watershed (38°49′N, 110°23′E) in Shenmu County, which is located in the center of the cropping-pastoral ecotone and wind–water erosion crisscross region (Fig. 1). The watershed has an area of 6.89 km^2 and is at an altitude between 1 081 and 1 274 m. The region has a semiarid continental climate with an average annual temperature of 8.4°C. Monthly mean temperatures range from −9.7°C in

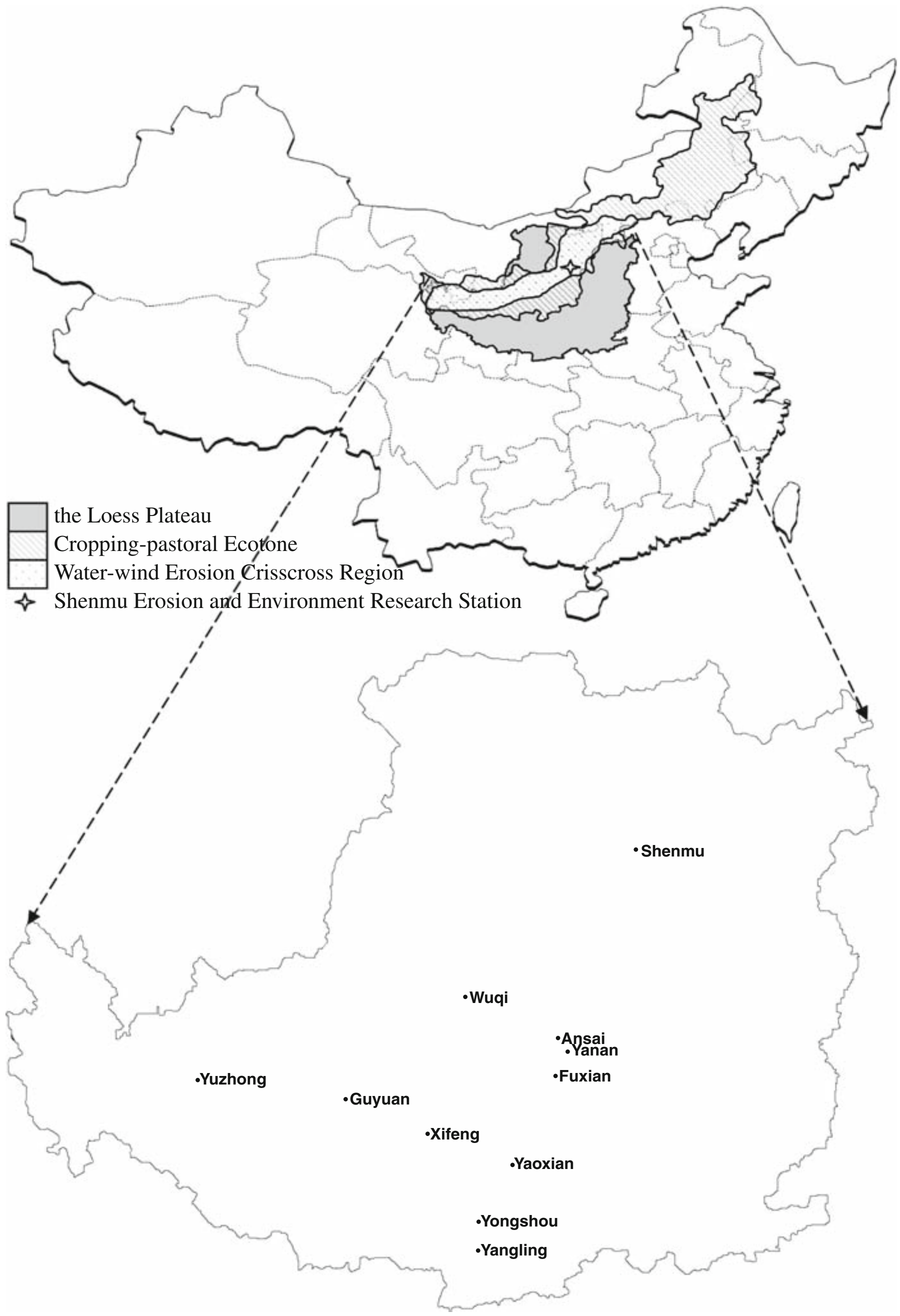

Fig. 1 The location of the study site, and the studies conducted across the Loess Plateau

January to 23.7°C in July. The average annual precipitation is 437 mm and 77% occurs from June to September.

The dominant native grasses are bunge needlegrass (*Stipa bungeana Trin.*) and Dahurian bush clover (*Lespedeza daurica* (*Laxm.*) *Schindl.*). From later 1970s, large amounts of Korshinsk Peashrub (*Caragana korshinskii*) and Chinese Pine (*Pinus tabulaeformis*) have been planted in degraded slopes to prevent soil erosion. At present, there is almost a natural recovery process with only slight disturbance from human beings and animals.

Field investigation, soil sampling and laboratory analysis

Three adjacent land use patterns, native grassland, Chinese Pine land and Korshinsk Peashrub land, were selected for study in September 2007. The native grassland is dominated by bunge needlegrass and Dahurian bush clover. Chinese Pine and Korshinsk Peashrub were established on the native grassland in 1979, 28 years prior to the present study. The soil for the three land uses is Light Castanozems, corresponding to Isohumosols and Kastanozems according to Chinese and FAO/ISRIC/ISSS Soil Taxonomy, respectively.

For each land use pattern, six plots (30 m × 30 m) were established. At each plot in Chinese Pine land and Korshinsk Peashrub land, five trees or brushes were randomly selected to determine their height, diameter (diameter at breast height, DBH, for Chinese Pine was measured at a height of 1.35 m, stem diameter of Korshinsk Peashrub was measured at the land surface) and canopy area. The average height, DBH and canopy area of Chinese Pine are 3.3 m, 10.0 cm and 3.0 × 3.3 m^2, while the average height, stem diameter and canopy area of Korshinsk Peashrub are 1.2 m, 1.3 cm and 106 × 89 cm^2, respectively. For the native grass land, five 2 × 2 m^2 subplots were established to measure grass canopy and aboveground biomass of grasses. The average canopy area and biomass for bunge needlegrass and Dahurian bush clover are 32%, 0.79 Mg ha^{-1} and 9%, 0.28 Mg ha^{-1}, respectively.

In each sampling plot, a 1.0-m long × 0.7-m wide × 1.0-m deep pit was dug for measuring soil bulk density using a 5.0-cm diameter by 5.0-cm height stainless steel cutting ring within 0–10, 10–20, 20–40, 40–60, 60–80 and 80–100 cm depths. Five representative soil profiles in each plot were randomly located within similar physiographic conditions and slope gradients. A total of 540 soil samples (6 replications × 3 land uses × 5 profiles × 6 soil layers, the same layer depth increments used for the bulk density) were collected with a 5.0-cm diameter tube auger. A 0.3–1.2 cm organic layer has developed in afforestation land, and we included it in 0–10 cm soil samples. Large pieces of non-decomposed organic matter were removed, and the moist field soil samples were brought to the laboratory. A subsample was stored at 4°C prior to extraction within 2 days of collection, the remaining soil was air dried and ground to pass through 2, 1 and 0.25 mm nylon screens prior to laboratory analysis.

Root biomass samples in each land use pattern were obtained near each soil-sampling location with a 9.0-cm diameter tube auger. Roots separated from the soil samples were dried at 65°C for 48 h to measure their dry weight.

Soil texture was determined by hydrometer method (Jury and Horton 2004). Concentrations of soil organic C, total N, total and extractable P were analyzed using standard methods. Soil organic C was determined using the Walkley–Black method (Nelson and Sommers 1982). Total N was measured using the Kjeldahl method (Bremner and Mulvaney 1982). Total P was determined colorimetrically after wet digestion with sulfuric acid and perchloric acid, and extractable P was determined by the Olsen method (Olsen and Sommers 1982). The moist soil was extracted by potassium chloride, and the extraction was analyzed immediately for ammonium nitrogen (NH_4^+–N) and nitrate nitrogen (NO_3^-–N) with a Lachat Flow Analyzer (AutoAnalyzer3-AA3, Seal Analytical, Mequon, WI) (Kachurina et al. 2000).

Stocks (Mg ha^{-1}) of soil organic C (SOC), N (STN) and P (STP) were calculated as follows (Zhou et al. 2007):

$$\mathrm{SOC}_i = \mathrm{D}_i \times \mathrm{BD}_i \times \mathrm{OC}_i/10$$

$$\mathrm{STN}_i = \mathrm{D}_i \times \mathrm{BD}_i \times \mathrm{TN}_i/10$$

$$\mathrm{STP}_i = \mathrm{D}_i \times \mathrm{BD}_i \times \mathrm{TP}_i/10$$

where D_i, BD_i, OC_i, TN_i and TP_i represent the thickness (cm), bulk density (g cm^{-3}), organic C (g kg^{-1}), total N (g kg^{-1}) and total P (g kg^{-1}), respectively, of the *i*th layer of soil.

In order to test our second hypothesis, we reviewed eight studies of soil organic C and total N concentrations in native grassland and afforestation land in the Loess Plateau. These eight studies had the same sampling scheme and laboratory analysis methods as our study in Shenmu. However, because the Chinese Pine growth was only available in Fuxian, we reviewed another two studies of Chinese Pine growth in the Loess Plateau (Yanan and Yangling). The geographic locations of these ten studies are also shown in Fig. 1. Detailed information for each study is presented in Table 1.

Table 1 Basic conditions of the studies across the Loess Plateau, and the organic C and total N concentrations in the 0 to 20 cm soil layers

Sites	Location	Annual mean temperature (°C)	Annual mean precipitation (mm)	Soil texture	Land use type	Age	OC g kg^{-1}	TN g kg^{-1}	Reference
Shenmu	110°22′, 38°49′	8.4	437	Sandy loam	Grass	28 a	2.34	0.44	This study
					Chinese Pine	28 a	1.68	0.28	
					Korshinsk Peashrub	28 a	1.83	0.38	
Yuzhong	104°25′, 36°02′	6.5	395	Loam	Grass	28 a	12.5	1.41	Guo et al. (2003)
					Korshinsk Peashrub	28 a	8.4	0.89	
Yongshou	108°05′, 34°48′	10.8	602	Clay loam	Grass	18 a	7.62	0.45	Zhang et al. (2006)
					Chinese Pine	44 a	38.38	0.55	
					Chinese Pine	18 a	12.12	0.6	
Fuxian	109°11′, 36°05′	9.0	576	Clay loam	Grass	28 a	18.28	1.9	Qiu (2007)
					Chinese Pine	28 a	40.04	1.52	
Yaoxian	108°50′, 35°10′	12.5	571	Clay loam	Grass	32 a	8.9	0.48	Geng et al. (2006)
					Chinese Pine	24 a	26.8	1.26	
					Chinese Pine	32 a	26.5	1.19	
Wuqi	107°90′, 36°90′	7.8	478	Loam	Grass	28 a	13.38	0.61	Yue et al. (2007)
					Chinese Pine	28 a	13.07	0.55	
					Korshinsk Peashrub	28 a	12.14	0.44	
Xifeng	107°37′, 35°42′	9.3	556	Clay loam	Grass	28 a	9.29	0.94	Qiu (2007)
					Chinese Pine	54 a	14.61	1.54	
Guyuan	106°28′, 35°80′	7.0	420	Loam	Grass	36 a	5.64	0.59	Qiu (2007)
					Korshinsk Peashrub	36 a	4.79	0.57	
Ansai	109°14′, 36°46′	8.8	505	Loam	Grass	30 a	6.59	0.77	Xue et al. (2007)
					Chinese Pine	30 a	6.42	0.66	
					Korshinsk Peashrub	30 a	5.74	0.71	
Yanan	109°28′, 36°36′	9.4	550	Loam	Chinese Pine	26 a	NA	NA	Liu et al. (2002)
Yangling	108°05′, 34°16′	12.9	631	Clay loam	Chinese Pine	20 a	NA	NA	Liu et al. (2003)

OC organic carbon, *TN* total nitrogen, *NA* not available

Statistical analysis

Two-way analysis of variance, correlation and regression analyses were conducted using SAS software (SAS Institute 1999). Two-way analysis of variance was used to test the land use and soil depth main effects and interaction effects on soil organic C and nutrients. Correlation analysis was used to evaluate the relationships between soil variables. Regression analysis was conducted to obtain the relationships between annual mean precipitation and temperature and the changes of soil organic C and total N after afforestation in the Loess Plateau.

Results

Similarity of soil organic C and nutrients before land use conservation in the study site

In this study, at each of the three adjacent land use pattern, the soil type was the same, the Chinese Pine and Korshinsk Peashrub were established on native grassland and no fertilizer had been applied to any of the land use systems since conversion. The selected plots had similar physiographic conditions and slope gradients. Additionally, the analysis of variance of soil organic C, total N and total P in the 40 to 100 cm soil layers indicated that there were no significant differences among land uses (Table 2). Therefore, the soils in the three land use patterns apparently had similar initial conditions, and subsequent differences in soil C, N and P at each site could be mainly ascribed to the differences in land use.

The effects of land use on soil organic C and nutrients

The contents of most soil variables decreased with soil depth in the northern Loess Plateau (Fig. 2). With increasing soil depth, the concentrations of organic C, total N, NO_3^-–N, extractable P and C/P decreased more in soils under native grass and Korshinsk Peashrub than under Chinese Pine. C/N decreased more in soils under native grass and Chinese Pine than under Korshinsk Peashrub, while NH_4^+–N and total P only changed slightly.

The organic C and total N concentrations in the 0 to 40 cm soil layer of Chinese Pine and Korshinsk Peashrub were significantly lower than that for native grass. The 40 to 100 cm soil layer had similar concentrations for all three land use patterns (Fig. 2; Table 3). The C/N ratio followed the order of Chinese Pine > native grass > Korshinsk Peashrub in the 0 to 20 cm soil layers, but native grass > Chinese Pine > Korshinsk Peashrub in the 20 to 100 cm soil layers. Similar to what was observed for organic C and total N concentrations, C and N stocks were significantly lower in the 0 to 60 cm soil layers under Chinese Pine and Korshinsk Peashrub than under native grass and exhibited no difference in the 60 to 100 cm soil layers (Fig. 3). Under the assumption that the C and N stock of the planted areas were equivalent to that of the native grassland prior to planting Chinese Pine and Korshinsk Peashrub, it may be concluded that the soil C and N stock decreased by 2.6 and 3.0 Mg C ha^{-1} (0.09 and 0.11 Mg C ha^{-1} $year^{-1}$) and 0.6 and 0.4 Mg N ha^{-1} (0.02 and 0.01 Mg N ha^{-1} $year^{-1}$) over the 28 years in the 0 to 60 cm soil layer, and by 2.8 and 3.4 Mg C ha^{-1} (0.10 and 0.12 Mg C ha^{-1} $year^{-1}$) and 0.6 and 0.4 Mg N ha^{-1} (0.02 and 0.01 Mg N ha^{-1} $year^{-1}$) in the 0 to 100 cm soil layer, respectively.

Throughout the 0 to 100 cm soil layer, concentrations of extractable P were lowest in Korshinsk Peashrub land but differed little in Chinese Pine land and native grassland, while the ratio of C/P always followed the order of native grass > Chinese Pine > Korshinsk Peashrub in the 0 to 60 cm soil layer. There were no significant differences in

Table 2 Analysis of variance of soil organic C, total N and P at various land use patterns in three soil layers

	OC			TN			TP		
	40–60 cm	60–80 cm	80–100 cm	40–60 cm	60–80 cm	80–100 cm	40–60 cm	60–80 cm	80–100 cm
F	0.700	0.040	0.300	0.110	0.310	0.220	0.150	0.050	0.030
p	0.534	0.962	0.752	0.897	0.745	0.808	0.863	0.948	0.971

OC organic carbon, *TN* total nitrogen, *TP* total phosphorous

Fig. 2 Profile distribution of the organic carbon and nutrients

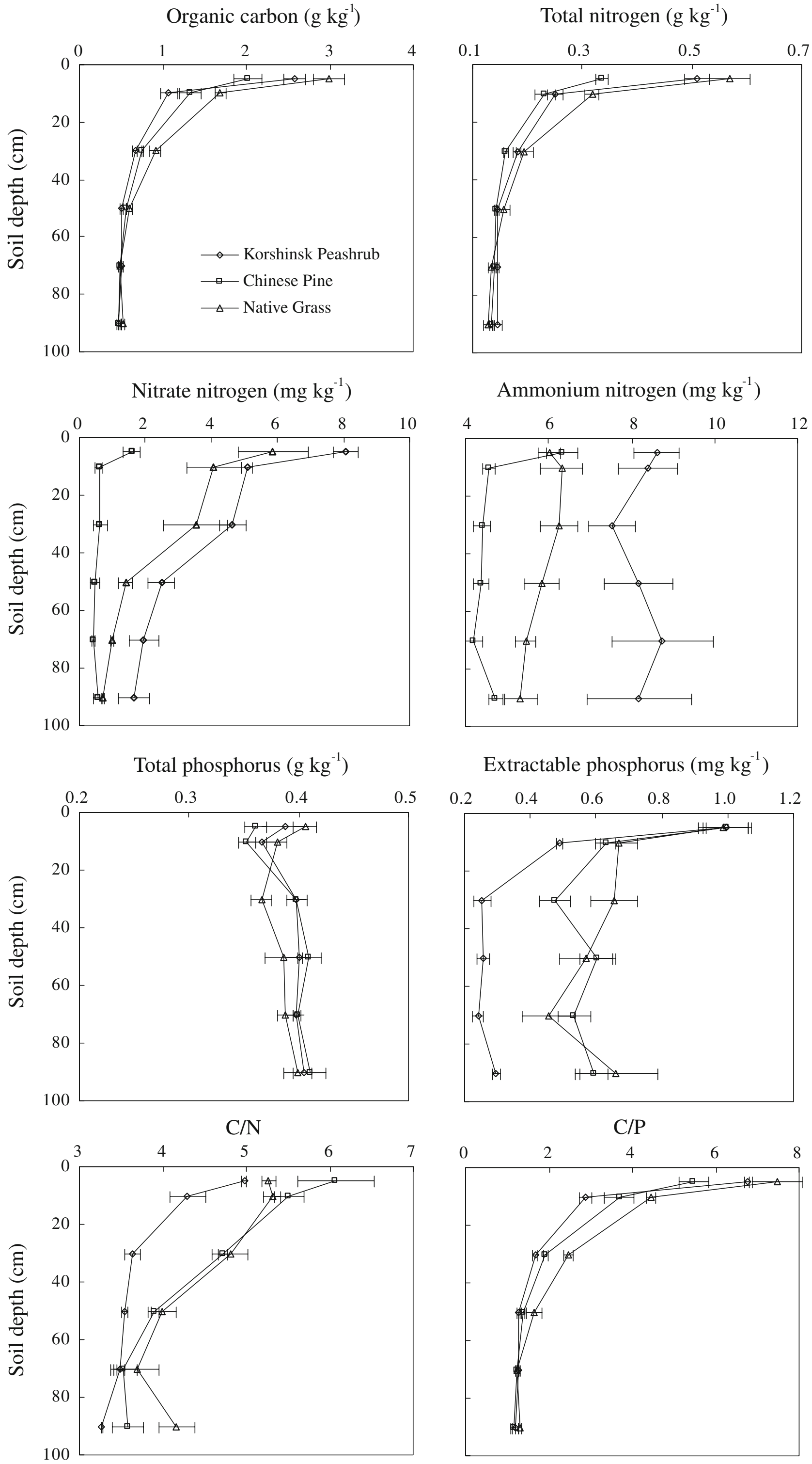

Table 3 Analysis of variance of soil organic C and nutrients as affected by land use and soil depth

	OC	TN	NO_3^-–N	NH_4^+–N	TP	EP	C/N	C/P
F								
Land use	3.3	5.13	14.66	10.63	0.14	5.67	5.54	4.11
Soil depth	52.71	50.24	7.1	0.22	0.75	7.28	10.78	62.8
Land use × Soil depth	1.22	2.35	1.12	0.16	0.5	0.42	0.62	1.1
p								
Land use	0.0481	0.011	<0.0001	0.0002	0.8725	0.0073	0.008	0.0246
Soil depth	<0.0001	<0.0001	0.0001	0.953	0.5913	<0.0001	<0.0001	<0.0001
Land use × Soil depth	0.3087	0.0295	0.3744	0.998	0.8753	0.9284	0.7842	0.3917

OC Organic carbon, *TN* total nitrogen, *NO_3^-–N* nitrate nitrogen, *NH_4^+–N* ammonium nitrogen, *TP* total phosphorous, *EP* extractable phosphorous

concentration and stock of total P with land use in the 0 to 100 cm soil layers (Table 3; Figs. 2, 3).

Comparison with other regions in the Loess Plateau

When determined either across or within the land use patterns, the concentrations of soil organic C and total N were considerably lower in the studied area than that at other locations in the Loess Plateau (Table 1). For example, organic C and total N of the 0–20 cm soil layers in the grassland of study site were 2.34 and 0.44 g kg^{-1}, while those of other sites ranged from 5.64 to 18.28 g kg^{-1} and from 0.45 to 1.90 g kg^{-1}, respectively.

Korshinsk Peashrub consistently decreased organic C and total N concentrations compared with grassland across all sites listed in Table 1. The effects of Chinese Pine varied with climatic factors. For sites with higher annual mean temperature and rainfall, Chinese Pine increased soil organic C and total N, while for sites with lower annual mean temperature and rainfall, Chinese Pine decreased soil organic C and total N.

Discussion

Land use effects on soil organic C and nutrients in the northern Loess Plateau

The soil C and N results supported our first hypothesis that soil organic C and nutrient conditions are significantly affected by land use change in the northern Loess Plateau. Soils under Chinese Pine and Korshinsk Peashrub had significantly lower organic C and total N than do soils under native grass, in the upper 0 to 40 cm soil layer. This is probably related in part to changes in amounts and forms of organic materials added to soils under different vegetation types (Condron and Newman 1998), as well as to higher losses of original soil C and N following the establishment of Chinese Pine and Korshinsk Peashrub. Mechanized site preparation can result in organic C and N losses (Aguilar et al. 1988) and promote the breakdown of the organic matter by accelerating the decomposition rates, reducing plant inputs or increasing soil erosion (Compton and Boone 2000). These losses of soil organic C and N may be large enough to offset gains in biomass C. Besides, the transition from native grass to Chinese Pine and Korshinsk Peashrub may result in a reallocation of C and N from belowground to aboveground and a shift in vegetation cover with grasses becoming shaded out by Chinese Pine and Korshinsk Peashrub. Grasses generally form extensive fine root systems, and the input of root biomass is considered to be the major contributor to organic matter and nutrients in grassland (Guo and Gifford 2002), while root production and turnover by Chinese Pine and Korshinsk Peashrub tends to be lower than that of grass. In this study, the fine roots (<2 mm) were mainly distributed in the 0–40 cm layer, which accounts for 79, 72 and 94% of the fine roots in the 0–100 cm layer in Chinese Pine, Korshinsk Peashrub and native grass lands, respectively (Fig. 4). Additionally, for the 0–40 cm soil layers, fine roots are 33 and 34% lower in Chinese Pine and Korshinsk Peashrub lands than

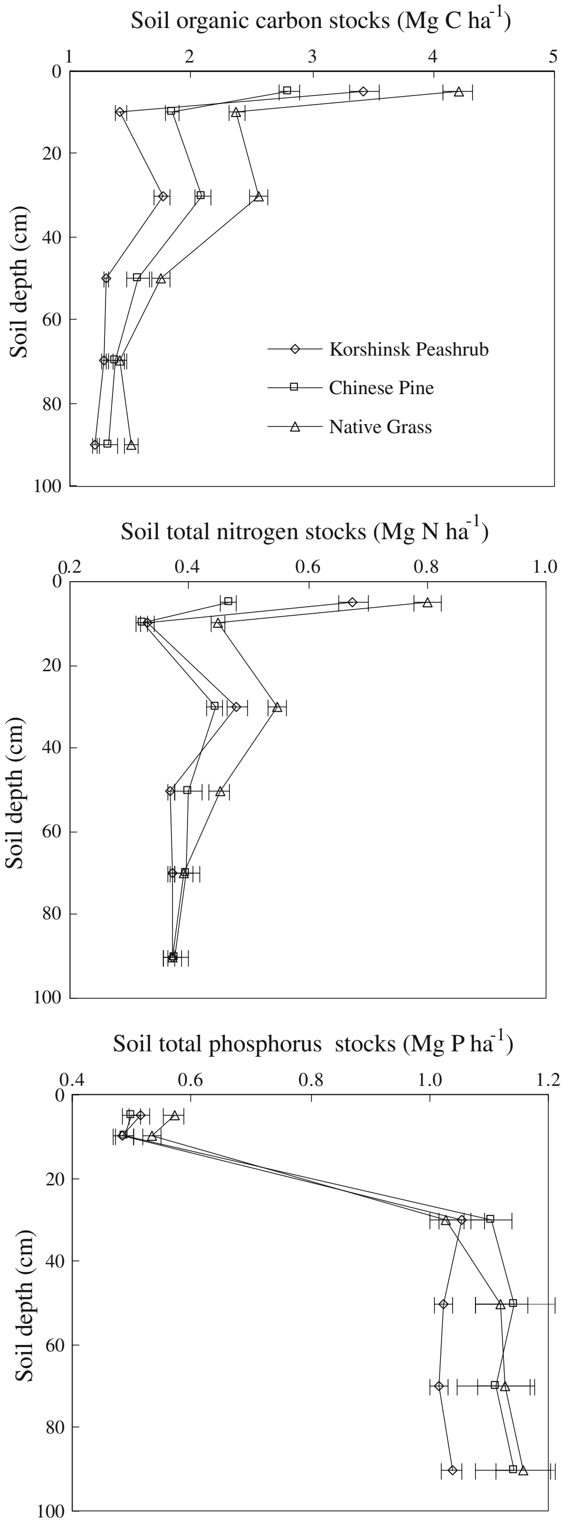

Fig. 3 Profile distribution of the stocks of organic carbon, total nitrogen and phosphorus

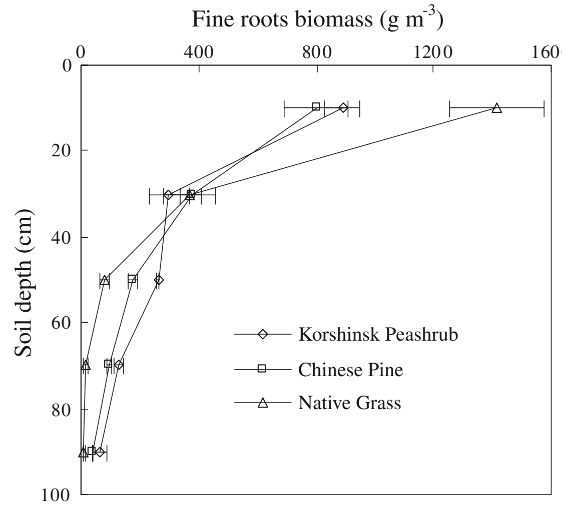

Fig. 4 Profile distribution of the fine roots biomass

that in grassland; while for the 0–100 cm soil layers, fine roots are 13 and 21% lower in both afforestation treatments. The profile distribution of fine roots agrees with the distributions of organic C and total N, suggesting that roots play an essential role in the response of soil organic C and N to land use changes in the northern Loess Plateau as well as other places.

In this study, the loss of soil organic C is greater than the loss of soil total N after 28 years of Chinese Pine and Korshinsk Peashrub. Powers (2004) also found that soils generally lost a higher proportion of organic C than total N upon cultivation. The differences in organic C and N loss could be ascribed to the low net nitrification, leaching and denitrification in this coarse textured soil, which results in low overall N losses.

In general, plant available N (NO_3^-–N, NH_4^+–N) was higher in soils under Korshinsk Peashrub but lower in soils under Chinese Pine compared with native grass. Korshinsk Peashrub is a N-fixing plant and can increase soil available N, resulting in a higher plant available N in soils, while Chinese Pine exhausts much of the available N in soils and decreases its content in soils, causing soil to have relatively small plant available N.

In the present study, soil total P was not found to differ significantly among land use patterns. This is in agreement with many other studies that reported slight or no change of soil total P with land use changes (Zaimes et al. 2008). However, extractable P was lower in soil under Korshinsk Peashrub and Chinese Pine than native grass, indicating that both plants used more available P than grass and led to decreases in soil. Meanwhile, the strongest decrease in extractable P was observed in Korshinsk Peashrub soils because legumes require more P than other plants for root development and energy driven processes since it enhances the symbiotic N fixation process (Al-Niemi et al. 1997). Therefore, more extractable P was utilized in Korshinsk Peashrub land and transported into the aboveground plant P pool. Although Dahurian bush clover also belongs to the Fabaceae, its effects on soil P can be neglected due to its low presence in the native grassland and low N fixation in the Loess Plateau (Zhang et al. 2008).

The C/N ratios in our experiment were lower than 10, indicating that low levels of organic materials were incorporated into the soil system (Saikh et al. 1998; Yimer et al. 2007). Nevertheless, in our experiment, the distribution trend of soil C/N ratios in various land uses is not consistent with that of organic C, total and plant available N because it was far below the critical ratio (25), below which net N mineralization is considered to occur (Chapin et al. 2002), indicating that C/N ratios respond slowly to land use patterns and can not reflect the changes of soil organic C and N nutritional conditions in the northern Loess Plateau.

The profile distribution of C/P ratios was determined by organic C and total P changes with land use patterns. Soils under Korshinsk Peashrub and Chinese Pine have lower organic C than under native grass, resulting in decreased C/P ratios. The C/P ratios were significantly related with extractable P ($r = 0.562$, $p < 0.001$), suggesting that C/P ratio can be used to indicate soil P availability in this study site. Additionally, the differences in C/N and C/P ratios with land uses indicate that more C than N and P was lost in Chinese Pine and Korshinsk Peashrub soils, which also resulted in the very low soil C/N and C/P ratios.

Comparison with other regions in the Loess Plateau

Our findings that the contents of soil organic C and total N were considerably lower in the studied area than at other locations in the Loess Plateau supported our hypothesis that soil organic C and total N in northern Loess Plateau are strongly different from those in southern Loess Plateau. There are several reasons for these conditions. One reason is the difference in soil texture. The soils in the study site are more sandy than most soils in the Loess Plateau, and the sandier soils contain less organic C, total N and total P than soils in the other regions of the Loess Plateau. Another reason is that extensive and intensive soil erosion enhanced soil nutrient losses in this study site. The Liudaogou watershed is located in the center of the wind–water erosion crisscross region, which suffered serious water erosion during the rainy seasons and wind erosion during strong windy days (Tang 2004). Wind and water erosion can cause significant losses of soil organic C and nutrients (Jacinthe et al. 2001). Although soil erosion also occurred in other regions of the Loess Plateau, the erosion intensity is the largest at this study site (Tang 2004). A third reason is related to differences in C and nutrient cycling in ecosystems. In our study site, the input of organic materials through litterfall and residues was lower than in other regions of the Loess Plateau due to the lower vegetation productivity (Table 4) and organic matter decomposition. Although the decomposition rate of organic material in the study sites was not available, it has been well established that the decomposition rate positively relates with temperature and rainfall (Austin 2002; Fang et al. 2005), while both climatic factors are all lower in the study sites than in southern parts of the Loess Plateau (Table 1). Therefore, the study site had less input of soil organic C and nutrients. Additionally, soil organic materials in sandy textured soils can

Table 4 Comparison of Chinese Pine growth at the study site (Shenmu) and at other locations in the Loess Plateau

Sites	Annual mean temperature (°C)	Annual mean precipitation (mm)	Age (year)	Height (month)	Diameter at breast height (cm)	Reference
Shenmu	8.4	437	28	3.3	10.0	This study
Yanan	9.4	550	26	9.6	17.0	Liu et al. (2002)
Fuxian	9.0	576	28	16.7	23.0	Qiu (2007)
Yangling	12.9	631	20	5.5	11.3	Liu et al. (2003)

have relatively rapid decomposition (Hofstede et al. 2002), which results in fast losses of soil organic C and nutrients.

As far as the effects of land use on soil organic C and total N are concerned, the effects of Korshinsk Peashrub are consistent across the Loess Plateau, while the effects of Chinese Pine differ with those in other locations of the Loess Plateau, also partly supporting our second hypothesis. The decreased soil organic C and total N by afforestation in northern Loess Plateau agree with many other studies conducted either in the Loess Plateau (Table 1) or in other regions of the world (Groenendijk et al. 2002; Jackson et al. 2002; Farley et al. 2004; Powers 2004). Powers (2004) observed that the conversion of pasture to *Vochysia guatemalensis* tree significantly reduced soil organic C in the 0 to 20 cm soil layer in Northeastern Costa Rica. Farley et al. (2004) found significant reduction in soil organic C after conversion of grassland to Pine plantations in the Ecuadorian Andes. Groenendijk et al. (2002) also reported the reduction in soil organic C and total N in New Zealand hill country soils 17 to 19 years following the conversion of pasture to *Pinus radiata*.

However, an increase in soil organic C and total N by the conversion of grass to trees was frequently reported. Macedo et al. (2008) found significantly increased soil organic C and N contents and stocks in Angra dos Reis, Rio de Janeiro after 13 years of leguminous nitrogen-fixing trees. Rhoades (2007) suggested that America Chestnut has the potential to increase soil organic C and N in silty and sandy loam soils in southwest Wisconsin. McGrath et al. (2001) determined increased soil organic C and N in forest land compared with grassland in Amazonia. In addition to deciduous trees, an increase in organic C and N by pine afforestation was also observed (Geng et al. 2006; Zhang et al. 2006; Qiu 2007). These increased soil organic C and N by both deciduous and pine trees might be a result of higher organic matter accumulation due to increased above- and belowground biomass and reduced litter decomposition rates (Saikh et al. 1998).

Although the effects of both pine and deciduous trees on soil might be different because of differences in their litter decomposition, either increases or decreases in soil organic C and N by both types of trees have been observed, so we attribute the discrepancies of land use effects on soil organic C and total N to the differences in climate which poses a significant role in C and N processes in ecosystems (Jobbágy and Jackson 2000; Dalias et al. 2001; Fang et al. 2005; Kirschbaum et al. 2008). At the Loess Plateau where rainfall ranges from 150 to 650 mm and annual mean temperature ranges from 4 to 14°C (Tang 2004), in areas with rainfall larger than 500 mm or temperature higher than 9.0°C, soils under Chinese Pine have significantly higher organic C and N than under grass, while in areas with rainfall less than 500 mm or temperature lower than 9.0°C, soils under Chinese Pine have lower organic C and N than under grass (Table 1). This is further supported by the linear increase in soil organic C and total N changes after afforestation with annual mean precipitation and temperature (Fig. 5).

Implications for land management and suggestions for further research

Results from this study demonstrate the potential for Chinese Pine and Korshinsk Peashrub to decrease soil organic C and total N relative to native grass. The decreases might continue with time for these land use patterns. This has important implications for land management in the area. The drought and cold climate as well as low nutrient and water availability at the study site would not favor Chinese Pine growth compared with other places in the Loess Plateau (Table 4). A phenotype variation investigation of Korshinsk Peashrub in the northwest and north China showed that leaf length is positively correlated with annual mean temperature, while number of leaves is positively correlated with annual mean precipitation (Song et al. 2005), suggesting that the growth of Korshinsk Peashrub in the study site is also lower than in regions with large precipitation and higher temperature. Therefore, planting Chinese Pine and Korshinsk Peashrub in native grass land in the northern Loess Plateau cannot form the required biomass for a sustainable ecosystem and cannot even maintain soil organic C and N. Hence, our results further indicate that a combination of low temperatures, little precipitation and large soil degradation impede increasing C and N stocks by afforestation and the afforestation on grassland should be viewed very critically in such areas.

Our study showed the distribution of soil organic C and nutrients in three adjacent lands. Further studies should be conducted to reveal changes in soils

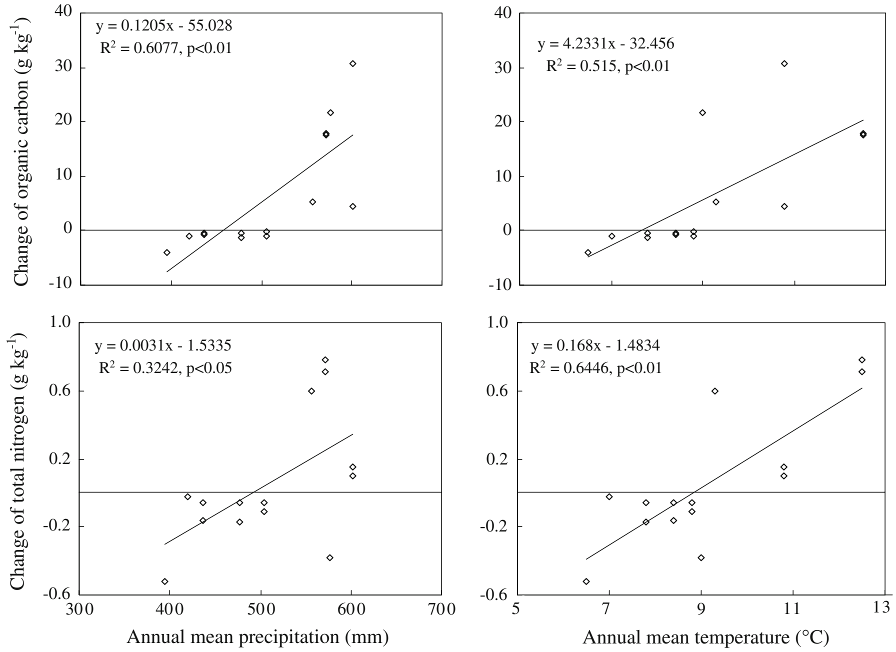

Fig. 5 Relationships between annual mean precipitation and temperature and changes of soil organic carbon and total nitrogen after afforestation in the Loess Plateau. *Positive values* indicate a gain of C, and *negative values* indicate a loss of C due to afforestation

organic C and nutrients at different times. This will provide dynamic traits of organic C and nutrients after land use change, and thus could be extrapolated to predict future changes of soil organic C and nutrients. Because land use conversion is usually accompanied by site preparation, both soil erosion and site preparation can alter organic C and nutrients, along with the vegetation change. We, therefore, recommend additional research to further evaluate these factors on soil organic C and nutrients.

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