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Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China

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Characterizing spatial variability of soil nutrients in relation to site properties, including climate, land use, landscape position and other variables, is important for understanding how ecosystems work and assessing the effects of future land use change on soil nutrients. In order to assess the effects of land use and landscape position on soil nutrients consisting of soil organic matter (SOM), total N (TN), total P (TP), available N (AN) and available P (AP), soil samples were collected in August and October 1998 and July 1999 from three transects in a small catchment on the loess plateau, China. The three transects consisted of typical land use structure from the top to foot of hillslope in the study area: fallow land – cropland – woodland – orchard (T1), fallow land – shrub land – fallow land – cropland – woodland – orchard (T2) and intercropping land – woodland (T3). Significant differences among land uses were found for SOM, TN and AN. Woodland, shrub land and grassland had the higher levels for them compared to fallow land and cropland. Use of soil deterioration index showed that soils deteriorated moderately (− 17·05%) under orchard and seriously (ranging from −29·91% to − 20·32%) under fallow land, cropland and intercropping land, while soils had no deterioration (− 0·74%) under shrubland and (− 0·69%) grassland. This study indicated that the cultivated hilly lands must be abandoned before a critical minimum SOM of 0·492%. Soil nutrient responses to landscape positions were variable depending on transect and the location of land use types. The highest levels in SOM, TN and AN were observed at middle slope position on T1, while they occurred at foot slope position on T3. However, an increasing trend from upper slope to foot slope for five nutrients were found on T2.

Keywords: soil nutrient; land use type; landscape position; soil deterioration index; loess plateau of China

Introduction

Understanding how nutrient resources vary across landscapes has become the focal point of much ecological research (Benning & Seastedt, 1995). Many studies have

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identified soil nutrient availability to be an important factor controlling net primary productivity (Pastor & Post, 1986; Seastedt *et al.*, 1991). Therefore, characterizing spatial variability and distribution of nutrients in relation to site characteristics including climate, land use, landscape position and other variables is critical for predicting rates of ecosystem processes (Schimel *et al.*, 1991), understanding how ecosystems work (Townsend *et al.*, 1995) and assessing the effects of future land use change on nutrients (Kosmas *et al.*, 2000).

Parent material (Kosmas *et al.*, 1993), climate and geological history are of major importance to affect soil properties on regional and continental scale. However, landscape position and land use may be the dominant factors of soil properties under a hillslope and small catchment scale. Landscape positions influence runoff, drainage, soil temperature, and soil erosion and consequently soil formation (Aandahl, 1948). Differences in soil formation along a hillslope result in differences in soil properties (Brubaker *et al.*, 1993), which can affect pattern of plant production, litter production and decomposition. All of these can further feed back on local C and N processes (Wedin & Tilman, 1990; Hobbie, 1996). Therefore, the variability of soil properties is large in complex hills (Miller *et al.*, 1988). Soil physical properties such as clay content distribution with depth, sand content and pH have been shown highly correlated with landscape position (Ovalles & Collins, 1986). Whereas organic matter has been shown to vary by slope position (Miller *et al.*, 1988; Bhatti *et al.*, 1991). Furthermore, Pierson and Mulla (1990) found that soils on foot slope and toeslope positions had a higher organic C content, greater aggregate stability, and a lower clay content than those on summit positions. Malo *et al.* (1974) reported that organic C content, clay content, and surface thickness increased from the shoulder position to the foot slope. Similar results were observed for prairie soils in Canada (Gregorich & Anderson, 1985).

Land use is an integrator of several environmental attributes which influence nutrients export (Young *et al.*, 1996). Land use and soil management practice influence the soil nutrients related soil processes, such as erosion, oxidation, mineralization, and leaching, etc. (Lepsch *et al.*, 1994; Fu *et al.*, 1999; Hontoria *et al.*, 1999), and consequently modify the processes of transport and re-distribution of nutrients. In noncultivated land uses, the type of vegetative cover is a factor influencing the soil organic carbon content (Grigal & Ohmann, 1992). Moreover, soils through land use change also produce considerable alterations (Fu *et al.*, 2000), and usually diminish soil quality after the cultivation of previously untilled soils (Davidson & Ackerman, 1993; Jaiyeoba, 1995). Thus, land use and type of vegetation must be taken into account when relating soil nutrients with environmental conditions (Hontoria *et al.*, 1999).

Most previous studies were conducted in temperate and tropical regions associated with weak soil erosion (Greenland & Nye, 1959; Ekanade, 1989; Kosmas *et al.*, 2000), but not in areas with a semi-arid climate like loess plateau of China with serious erosion. The particular nature of the typical loess relief, with slopes subject to cultivation many years ago, has led to serious soil erosion. As the soil is eroded, land use is usually shifted from cropland to fallow land (grassland) due to increasingly poor yields from the various agricultural crops. Land use conversion and landscape position associated with erosion resulted in high variability of nutrients. It is, therefore, a special and interesting area for the performance of an integrated analysis of soil nutrients in relation to land use and landscape position. Such a local analysis is necessary to estimate nutrient storage in semi-natural and cultivated ecosystems and potential changes in nutrient contents due to land use change in regional scale.

We hypothesized that a wide array of soil nutrients may vary among land uses and landscape positions. The objectives of this study were (1) to assess the effects of land use and landscape position on soil nutrients including Soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP), avaiable nitrogen (AN) and available phosphorus (AP); and (2) to explore key indicator for protection from land deterioration.

Materials and methods

Study area

The Da Nangou catchment (36°53′N; 109°19′E) is situated on the middle part of the loess plateau in northern Shaanxi province, China. The catchment consists of a main valley with four larger valleys where several smaller valleys end. It has an altitude of 1000–1350 m with an total area of 3·5 km^2 encompassing two villages. There are significant topographic variations with typical loess hills and gully landforms within the study area. A Digital Elevation Model (DEM) map from topographical map provides data on slope angle and relative elevation (Fig. 1).

Chen *et al.* (in press) reported that land uses experienced several changes in history at the study area. Before 1958, woodland coverage was the largest and then dropped sharply due to the 'Great Leap Forward' movement and the 'Cultural Revolution'. Most of the woodlands have been exploited for crops and the others were planted for shrubs and grasses. Terrace farmlands were built during the 1958–1981 period. After the land reform in 1981, the woodland area increased a little. Moreover, orchards were developed in order to increase incomes. At present, land use types are slope cropland, fallow land, grassland, shrub land, orchard land, intercropping land and woodland in the study area. Crops are mainly potatoes (*Solanum tuberosum*), beans (*Glycine max*), maize (*Zea mays*) and millet (*Panicum miliaceum*). Fertilizer management for crop included a preplant application of 50 kg ha^{-1} as anhydrous NH_3 and 2252 kg ha^{-1} of manure (green manure + animal manure), and 20 kg ha^{-1} P in middle growing season. Crop yields are low, with great variability depending on the rainfall. The forest, artificial woods, is dominated by locust trees (*Robinia pseudoacacia*). The grassland is mainly covered by annuals such as sweet wormwood (*Artemisia annua*), annual fleabane (*Erigeron annuus*) and sandy needlegrass (*Stipa glareosa*). Littleleaf peashrub (*Caragana microphylla*) in shrub land and apple tree (*Malus pumila mill*) in orchard are present. Fallow land slowly came into being after cultivated plots were abandoned several years ago.

The region has a semi-arid continental climate with an average annual temperature of 8·8°C. Monthly mean temperatures range from 22·5°C in July to −7°C in January. The average annual precipitation is 562 mm with maximum and minimum recorded values of 645·0 mm (1978) and 296·6 mm (1974) respectively. Sixty percent of the rainfall falls between July and September. There are 144 frost-free days and an average of 2397·3 hours of sunshine each year in this study area.

Soil of the study area developed on wind-accumulated loess parent material. According to FAO-UNESCO soil classification system, it is classified as Calcic Cambisol. The soil in the catchment is characterized by a texture of silt ranging from 64% to 73% and clay varying from 17% to 20%. It is weakly resistant to erosion. The erosion rate is extreme seriously at about 10,000–12,000 t km^{-2} yr^{-1} (Song *et al.*, 1989). Due to serious soil erosion, the ground surface has been incised strongly with rill and gully erosion developed well.

Soil sampling and measurements

Three hillslopes, distributing typical land use structure, were selected for collecting soil samples. The land use combinations from the top to foot of the hill were: south-facing fallow land – cropland – woodland – orchard; north-facing fallow land – shrub land – fallow land – cropland – woodland – orchard and north-facing intercropping land – woodland. A total of 33 sample points were selected (Fig. 1). Based on the six categories of landscape positions including upper interfluve, lower interfluve, shoulder, upper linear, lower linear, and foot slope used by Brubaker *et al.* (1993, 1994), we divided the hillslope into three positions, upper slope (US), middle slope (MS) and foot slope (FT).

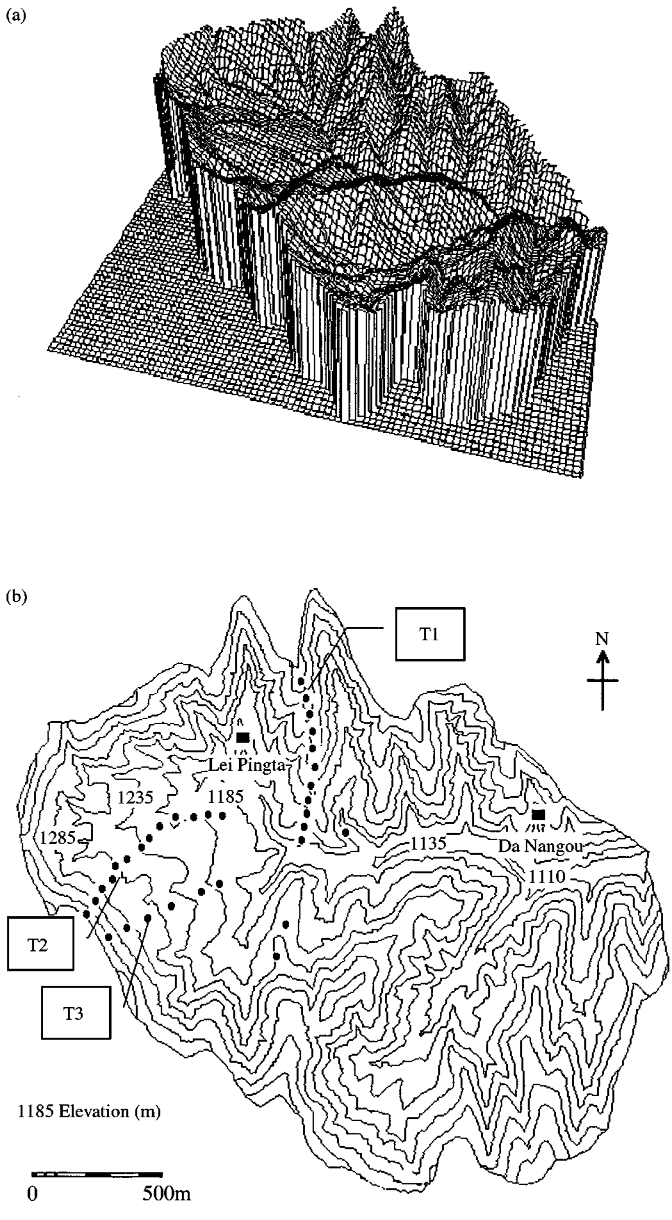

Figure 1. (a) Digital elevation model and (b) spatial distribution of sampling sites in the Da Nangou catchment. T1, transect 1; T2, transect 2; T3, transect 3; ■, village; ●, sampling point.

The US position, relative to upper interfluve and lower interfluve, is the uppermost portion of the hillslope. It receives little or no overland flow but may contribute runoff to downslope position. The MS position including shoulder, upper linear and lower linear receives overland flow from the upper slope and contribute runoff to the FT slope. The FT represents the base of the hill. Water and sediment running off the FT may enter a waterway or other water conveyance systems.

In August and October 1998 and July 1999, surface soils were collected for the same 33 plots respectively. Samples of 0–20 cm depth below the litter (or where soil surface where no litter existed) were taken from five points within each plot using a 20 × 5 cm soil corer. The five replicate samples were homogenized by hand mixing. About 1-kg mixed samples were returned to the laboratory at Ansai Field Station within 7 km of the study site. Major live plant materials (roots and shoots) and pebbles in each sample were separated by hand and discarded. The soil samples were air-dried, then passed through 1·0- and 0·25-mm sieves for determination of soil nutrients. Standard soil test procedures for observation and analysis in Chinese ecosystem research network were used for the five soil nutrients (Editorial Committee, 1996). TN was determined by the semi-micro Kjeldahl method, and TP was determined colorimetrically after wet digestion with $H_2SO_4 + HClO_4$ (Parkinson & Allen, 1975). Available N was determined by using a micro-diffusion technique after alkaline hydrolysis (Conway, 1978). AP was determined by Olsen method (Emteryd, 1989). SOM was determined by oil bath-K_2CrO_7 titration method (Nelson & Sommers, 1975).

Calculation of soil deterioration indices

The soil deterioration index reported by Adejuwon & Ekanade (1988) was computed on the assumption that the level of individual soil nutrients under fallow land, cropland, orchard, shrub land, intercropping land and grassland was once the same as that of soils under woodland before conversion. The difference between mean values of individual soil nutrients under the six land uses above mentioned compared to base values of soil nutrients under woodland was calculated and expressed as a percentage of the base values of individual nutrients. These percent values were then averaged across all soil nutrients to compute the soil deterioration index. Values for SOM, TN and TP were included in this calculation because they safely and suitably reflect the soil fertility.

Statistical analysis

Statistical analyses were performed to test the influence of land use and landscape position on soil nutrients using one-way ANOVA, and mean comparisons were made using the least significant difference (LSD) method with $p < 0{\cdot}05$. The independent variables used in this study were land use types, landscape positions and slope aspects. Significance of both of their interactive effect was identified using GLM-MANOVA. All the analyses were conducted through SPSS program (SPSS Inc., 1993).

Results

Soil nutrients and land uses

On seasonal average, the soil nutrients of non-cultivated lands including fallow land, woodland, shrub land and grassland, and cultivated lands consisting of cropland, orchard and intercropping land differed considerably in SOM, TN, AN and AP (Table1). The higher SOM, TN and AN contents occurred in non-cultivated lands than those under cultivated lands. Their highest values corresponded to woodland, shrub land and grassland in noncultivated lands. Fallow land had the lowest soil nutrient contents. The results indicate that cultivation decreases soil nutrient levels, as has been noted by many authors (Davidson & Ackerman, 1993; Lepsch *et al.*, 1994; Zheng *et al.*, 1996). There were statistically significant differences in SOM, TN and AN among the seven land use types (Table 1). The mean SOM content varied between 0·492 and

Table 1
Seasonal averages of soil nutrients for seven land use types

Nutrients §	SOM (%)	TN (%)	TP (%)	AN (mg/100g)	AP (mg/kg)
Non-cultivated land uses	0·790	0·045	0·060	3·669	1·153
Cultivated land uses	0·544	0·034	0·060	2·730	2·291
F value	14·859**	10·367**	0·516	10·272**	4·571*
Land uses #					
FAD	0·492a	0·029a	0·058a	2·617ac	1·172a
CRD	0·515a	0·033a	0·059a	2·626a	1·748a
ORD	0·628ac	0·038ac	0·061a	2·777ac	3·348a
WOD	0·865b	0·051bcd	0·062a	3·931bd	1·173a
SHD	0·883bcd	0·049bce	0·060a	4·055cd	1·193a
IND	0·546ade	0·037ade	0·063a	3·081ad	3·057a
GRD	0·881bce	0·050bce	0·059a	3·942cd	1·010a
F value	4·448**	3·732**	0·960	2·974*	2·054

Values in each column with the same letter are not significantly ($p < 0{\cdot}05$, LSD) different among land uses.

* ** Significant at the 0·05, and 0·01 level, respectively.

§ SOM – soil organic matter; TN – total nitrogen; TP – total phosphorus; AN – available nitrogen; AP – available phosphorus.

FAD – fallow land; CRD – cropland; ORD – orchard; WOD – woodland; SHD – shrub land; IND – intercropping land; GRD – grassland.

0·883%. Multiple comparisons of SOM revealed that SOM level under woodland, shrub land and grassland was significantly higher compared to fallow land and cropland. Seasonal averages of TN (0·029–0·051%) and AN (2·617–4·055 mg $100g^{-1}$) displayed similar patterns to SOM for multiple comparisons. This similarity may be related to SOM influencing nutrient retention and supply (Brubaker *et al.*, 1993). Mean TP content did not show marked difference among land uses. Although AP for seven land use types was not statistically significant through ANOVA test (Table 1), high values tended to occur in orchard and intercropping land with fruit trees. The same patterns for AP in three sampling dates were observed from Table 2. In addition, close inspection of Table 1 and Table 2, five nutrients exhibited similar results of ANOVA and multiple comparisons for three sampling dates, which suggests that differences in land uses really result in differences in nutrient levels.

As the soil deterioration index reflects the percent changes in soil nutrients from their values under woodland, it can be regard as an indication of soil deterioration (improvement) degree. The positive value shows improvement of the soils, whereas negative value indicates deterioration of the soils. If the index is greater than −5%, this indicates no deterioration for soils. The soils have light deterioration for the index between −5% and −10%, moderate deterioration ranging from −10% to −20% and serious deterioration less than −20%. The soil deterioration indices varying between −0·69% and −29.91% (Fig. 2) showed that the soils under those land uses had deterioration in some extent. The indices for soils under shrub land and grassland were close to zero (−0·74% and −0·69%), indicating no deterioration. In contrast, moderate deterioration in orchard (−17·05%) and serious deterioration in fallow land (−29·91%), cropland (−26·26%) and intercropping land (−20·32%) occurred. These soil deterioration indices clearly indicate that moderate and serious deterioration is measured in soil quality when woodland is exploited for agriculture.

Table 2
Comparisons of soil nutrients for the seven land use types on three sampling dates

Land uses #	SOM (%)	TN (%)	TP (%)	AN (mg 100g⁻1)	AP (mg kg⁻1)
	Nutrients § (13 Aug. 1998)				
FAD	0·496a	0·031a	0·062a	2·407ac	1·537a
CRD	0·576ac	0·036ac	0·061a	2·286a	2·007a
ORD	0·578ad	0·036ad	0·061a	2·445ac	3·593a
WOD	0·838b	0·050b	0·064a	3·740bd	1·446a
SHD	0·843bcd	0·051bcde	0·062a	4·210be	1·520a
IND	0·496a	0·033ae	0·063a	2·720acd	2·887a
GRD	0·964b	0·055b	0·058a	3·805cde	1·050a
F value	3·646**	3·186*	0·341	4·396**	2·059
	Nutrients § (10 Oct. 1998)				
FAD	0·521ac	0·027a	0·057a	3·270a	0·687a
CRD	0·493a	0·029a	0·060a	3·385a	1·016a
ORD	0·558ac	0·032ac	0·063a	2·715a	2·820b
WOD	0·871bd	0·047bd	0·064a	4·177a	0·883a
SHD	1·066be	0·049bce	0·061a	4·525a	0·945a
IND	0·581ac	0·033ade	0·066a	3·060a	2·537b
GRD	0·831cde	0·044ade	0·063a	3·910a	0·710a
F value	6·327**	3·424*	2·101	1·475	5·078**
	Nutrients § (7 Jul. 1999)				
FAD	0·460ac	0·031a	0·055a	2·173ac	1·293a
CRD	0·476a	0·033a	0·056a	2·208a	2·222a
ORD	0·750acd	0·046ac	0·060a	3·170acd	3·630a
WOD	0.885bde	0·053bcd	0·059a	3·876bde	1·191a
SHD	0·741ace	0·046ad	0·057a	3·430ace	1·115a
IND	0·559ace	0·043ad	0·060a	3·463ace	3·747a
GRD	0·848ce	0·050ad	0·056a	4·110ce	1·270a
F value	3·157*	3·014*	1·236	2·604*	0·996

Values in each column with the same letter are not significantly ($P < 0·05$, LSD) different among land uses.
*,** Significant at the 0·05, and 0·01 level, respectively.
§ and # See Table 1 for abbreviations.

Soil nutrients and landscape positions

There were no significant differences in soil nutrients among landscape positions on T1 (Table 3). Close observation suggests that there is a tendency for greater values in nutrients at the MS position. Moreover, all soil nutrients except for AP exhibited similar pattern on T1 for three sampling dates.

Land use types of T2 were much different than that of T1. Significant differences among landscape positions were observed for five nutrients on the third sampling date, but not on the first sampling date except for TP and the second sampling date. Comparisons of soil nutrients by landscape positions on 7 July (Table 3) revealed that SOM, TN, TP, AN and AP contents on FT slope were significantly higher than those on US and MS positions. The lowest levels in TN, AN and AP occurred on the US position. Although differences for most of nutrients among landscape positions

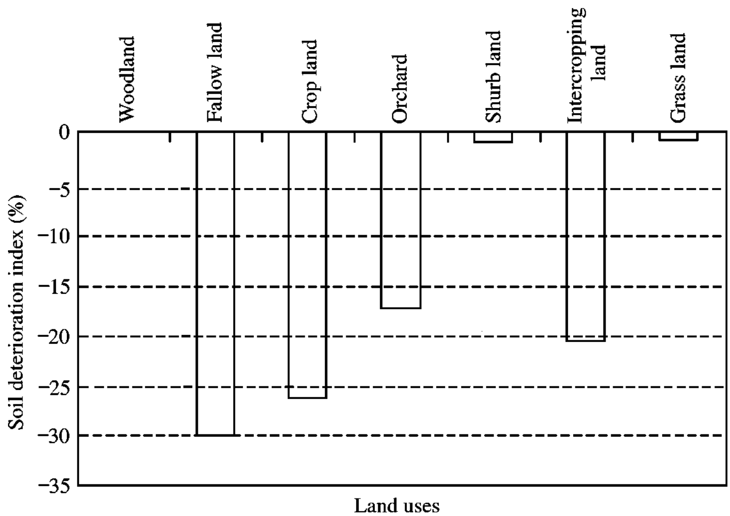

Figure 2. Soil deterioration index for different land uses in Da Nangou catchment.

were not statistically significant on the first and second sampling dates, they tended to the highest value on foot slope and the lowest on upper slope, having similar patterns of nutrients to those on the third sampling date.

In contrast to T1 and T2, T3 had the simplest land use structure. There was a similar trend in soil nutrients along slope to T2 (Table 3). Most nutrients tended to be on the higher levels on FT slope and the lower levels on US position. More pronounced was that no significant differences among landscape positions on three sampling dates were found for five nutrients except for AP on 13 August, and that highest concentration of AP occurred on US position.

Soil nutrients were averaged to obtain transect level estimates of fertility. Significant difference was found for TP among three transects. Comparisons of TP showed that TP contents on T2 and T3 were significant higher compared to T1 (Table 4). In contrast, SOM, TN, AN and AP were no statistical differences among the three transects. MANOVA results indicated that significant differences in TP and AP for aspects and AP for the interaction of land uses and aspects were found, but not in SOM, TN and AN.

Soil nutrient correlation

Many measurements in this study were significantly correlated with each other (Table 5). AP was not almost correlated with SOM. However, TN, AN and TP were positively and significantly correlated with SOM. The similar distribution patterns of TN and SOM along slope (Table 3) may indirectly prove their highest correlation coefficient (0·94). Total N was positively and significantly correlated with TP, AN and AP. The correlation coefficients with TP were significant, 0·43 for AN and 0·29 for AP. No significant correlation of AN and AP was found.

Discussions and conclusions

As Table 1 showed, woodland, shrub land and grassland had significant differences in SOM, TN and AN compared to fallow land and cropland. In the present case, land

Table 3

Comparisons of soil nutrients for the landscape positions on three sampling dates

Nutrients §		SOM (%)			TN (%)			TP (%)			AN (mg 100g^{-1})			AP (mg kg^{-1})		
Transect	Position	13 Aug. 98	10 Oct. 98	7 Jul. 99	13 Aug. 98	10 Oct. 98	7 Jul. 99	13 Aug. 98	10 Oct. 98	7 Jul. 99	13 Aug. 98	10 Oct. 98	7 Jul. 99	13 Aug. 98	10 Oct. 98	7 Jul. 99
	Upper slope	0·539a	0·463a	0·435a	0·034a	0·025a	0·032a	0·059a	0·057a	0·055a	2·105a	3·575a	2·270a	0·995a	0·840a	1·230a
1	Middle slope	0·579a	0·632a	0·638a	0·037a	0·036a	0·040a	0·059a	0·059a	0·054a	2·689a	3·219a	2·629a	1·714a	1·094a	1·391a
	Foot slope	0·533a	0·466a	0·623a	0·033a	0·027a	0·039a	0·058a	0·063a	0·057a	1·945a	2·225a	2·545a	2·070a	1·995a	0·465a
	F value	0·113	0·760	0·429	0·403	0·928	0·240	0·020	0·367	0·333	0·806	1·598	0·067	4·077	2·129	2·583
	Upper slope	0·618a	0·536a	0·553a	0·038a	0·029a	0·034a	0·059a	0·061a	0·054a	2·820a	2·910a	2·445a	1·570a	0·505a	1·130a
2	Middle slope	0·662a	0·666a	0·513a	0·041a	0·037a	0·035a	0·063a	0·062a	0·057a	2·983a	4·110a	2·445a	2·065a	1·045a	1·755a
	Foot slope	0·954a	0·819a	1·138b	0·057a	0·045a	0·067b	0·070b	0·061a	0·065b	3·483a	4·443a	4·807b	4·357a	2·340a	6·323b
	F value	1·956	0·563	8·555**	2·082	0·848	9·509**	4·349*	0·150	17·309**	0·220	1·153	6·084*	2·665	1·834	3·954*
	Upper slope	0·466a	0·541a	0·542a	0·031a	0·031a	0·044a	0·061a	0·065a	0·060a	2·505a	2·715a	3·880a	2·990a	3·175a	3·910a
3	Middle slope	0·687a	0·740a	0·672a	0·045a	0·041a	0·046a	0·064a	0·067a	0·061a	3·360a	3·785a	3·015a	2·365a	0·945a	2·490a
	Foot slope	0·759a	0·794a	0·755a	0·042a	0·042a	0·047a	0·062a	0·064a	0·060a	3·490a	3·820a	3·655a	0·815b	0·890a	1·010a
	F value	3·052	2·633	1·674	1·646	2·652	0·123	0·358	0·350	0·056	6·079	6·727	0·345	20·847*	5·180	2·054

Values in each column with the same letter are not significantly ($p < 0·05$, LSD) different among landscape positions.
*,** Significant at the 0·05, and 0·01 level, respectively.
§ See Table 1 for abbreviations.

Table 4
Averages on soil nutrients for three transects

Nutrients §	Transect 1	Transect 2	Transect 3	*F* value
SOM (%)	0·577a	0·689a	0·661a	0·776
TN (%)	0·035a	0·041a	0·041a	0·968
TP (%)	0·058a	0·061b	0·063b	4·015*
AN ($mg\,100g^{-}1$)	2·699a	3·355a	3·358a	1·882
AP ($mg\,kg^{-}1$)	1·351a	2·164a	2·066a	1·003

Values in each row with the same letter are not significantly ($p < 0{\cdot}05$, LSD) different among transects
*Significant at the 0·05, and 0·01 level, respectively.
§ See Table 1 for abbreviations.

Table 5
Correlation between soil nutrients

	Soil organic matter	Total N	Total P	Available N	Available P
Soil organic matter					
Total N	0·94**				
Total P	0·42**	0·39**			
Available N	0·80**	0·77**	0·43**		
Available P	0·10	0·21**	0·29**	0·06	

Numbers are correlation coefficients (r). Number of observation (n) = 99.
** Significant at the 0·05, and 0·01 level, respectively.

use for cultivation is related to soil management practices that have commonly been very destructive to the soil and have caused serious erosion. Therefore, differences in soil erosion control of land use (Jiang *et al.*, 1996) in such a erosion risky area (Fu, 1989; Fu & Chen, 2000), may contribute to the significant differences in nutrients for non-cultivated and cultivated soils. In addition, a combination of lower C inputs because of less biomass C return on harvested land, increased aeration by tillage and crop residue collecting partly causes the reduction of SOM, TN and AN in cultivated soils (Mullar-Harvey *et al.*, 1985; Girma, 1998). Unlike SOM, TN and AN, there was no significant difference for TP and AP among these land uses. TP content with narrow range within 0·05 and no differences among land uses may be due to the fact that most of P is held very firmly in crystal lattices of largely insoluble forms, such as various Ca, Fe and $AlPO_4^-$ s, and also is chemically bonded to the surface of clay minerals (Chen & Zhang, 1991). However, the high AP content tended to exist in land uses with fruit trees. Similar patterns were observed in three sampling dates (Table 2). It seems likely that more mycorrhizal roots in crops especially in leguminous plants compared to apple trees increase the efficiency of P absorption (Pacovsky, 1986; Gnekow & Marschner, 1989). Moreover, the kinetics of P uptake into hyphae may have a higher affinity of uptake leading to more effective absorption from low concentrations in the soil solution (Harley, 1989).

Soil deterioration indices well and truly reflect the differences in soil quality for land uses. For example, woodland, shrub land and grassland had the higher contents of SOM, TN and AN compared to fallow land and cropland. Whereas the soil deterioration indices of the former, 0 for woodland, −0·74% for shrub land and −0·69% for grassland, were greater than that of the latter, −29·91% for fallow land and −26·26% for cropland. The higher fertility was observed in intercropping land among cultivated land, and its deterioration index was −20·32% less than cropland. This implies that intercropping system is a better cultivation practice in semi-arid environments.

Among soil properties, total organic C was sensitive soil quality indicator suggesting that within a narrow range of soil, it may serve as a suitable indicator of soil quality (Murage *et al.*, 2000). Moreover, soil organic matter fraction may offer further insight into soil fertility changes and the sustainability of past management history (Barrios *et al.*, 1996; Kapkiyai *et al.*, 1998). In this study, soils from woodland, shrub land and grassland contained significantly greater organic matter compared to those from fallow land and cropland. Cropland is usually abandoned for fallow due to increasingly poor yields from the various agricultural crops. Moreover, the lowest fertility occurred in fallow land among seven land uses (Table 1), and its deterioration index indicated serious deterioration. Therefore, organic matter in fallow land may provide threshold value for soil fertility protection. Below this threshold the crops grow weakly and their yields are very low and where the erosional processes may be active, resulting in further soil fertility loss and land degradation. It can be inferred that the average soil organic matter of 0·492% in fallow land must be considered as key indicator for abandonment of hilly cultivated land under present management practices and existing climate conditions of the study area. In the case of shifting from cropland to fallow land, grassland and shrub land, soils begin to recover after fallow, these lands would change into grassland and shrub land several years later. So it can be assumed that the current averages of soil nutrients in fallow land and grassland respectively is representative of this scenario of land use conversion. During the process of this conversion, although soil nutrients showed lower level in fallow land, soil fertility would gradually recover and reach to relatively higher level in grassland with deterioration index close to zero. In the future, an increase of soil nutrients would be expected as a result of alternative cultivation practices such as developing intercropping system, building terrace for soil and water conservation and return of cropland to grassland and woodland. Since land uses play an important role in soil nutrient accumulation and losses (Fu *et al.*, 1999; 2000), the relationships among soil nutrients, land use management practices and land use history would be helpful for the study of land use change, and need further research.

At the loess plateau, it is commonly presumed that the interactions of climate, parent material, land use type (vegetation type), topography and cultivation practices result in complex spatial patterns of soil nutrients. Under transect level, our results suggest that soil nutrient patterns and responses to landscape position were variable depending on transect and land use type. For example, the higher levels in SOM, TN and AN were found at MS position on T1 (Table 3). Such a result is surprising in such a serious erosion area, as the high nutrients would be expected from the little effects of potential erosion on the soil nutrient losses. This result may be explained by the land uses influence on soil erosion. Woodland locating in MS position usually decreases runoff occurrence (Jiang *et al.*, 1996; Dong *et al.*, 1998) and deposits part of soil dissolved matter in runoff, and therefore has the higher nutrient contents. In contrast, the high contents of SOM, TN and AN occurred in FT slope on T2 and T3. Higher nutrient contents on FT slope may result from deposition of nutrients from US position and higher levels of plant production and residue (Brubaker *et al.*, 1993). Moreover, an increase trend from US to FT slope for all nutrients was observed on T2, and significant differences among landscape positions were found on 7 July (Table 3). The absence of consistency in nutrients with landscape positions across three transects are not in agreement with previous studies (Northcote, 1954; Brubaker *et al.*, 1993). There are two possible reasons for the differences. First, simple land use was in their studies, but multiple land uses in our study. The dominant control for soil nutrients resulting from land uses partly overcome the impacts of landscape positions on them. Second, micro-topographic features such as rills and ephemeral gullies due to serious soil erosion may obscure the effects of landscape positions on nutrients along hillslope.

Our results demonstrated that greater average on contents for all soil nutrients were measured in T2 and T3 relative to T1 (Table 4). Significant difference in TP was observed between the two transects and T1. MANOVA results showed that significant differences were found in north and south facing slope for TP and AP, and in the interaction of land uses and aspects for AP. This indicated that the differences in the radiation intensity between the north and south facing slopes resulted in the differences in P contents.

Some of soil nutrients were significantly correlated with each other (Table 5). Higher correlation of TN and AN with SOM may be explained by the SOM contribution to the pool of total and potentially mineralizable N, and further influence on their retention and supplying power in soils.

In conclusion, this study assessed the effects of land use and landscape position on soil nutrients. Significant differences among land uses were found for most soil nutrients. Soil Organic Matter, TN and AN contents had the higher levels in woodland, shrub land and grassland than those in fallow land and cropland. While no marked differences in TP and AP occurred among land uses. The soil deterioration index analysis indicated that soils would occur from moderate to serious deterioration when woodland is exploited for agriculture. Under the present land use management and climate conditions of the study area, the cultivated hilly lands must be abandoned before soil organic matter content is depleted to a critical value of 0·492%. Because it is too low to sustain economic yield of crops, and erosional processes may be very active resulting in further degradation. At the transect level, land use and landscape position resulted in more complex patterns of soil nutrient distribution. Because of the complex nature of soil nutrient patterns largely depending on the land uses and landscape positions, additional research is needed to more fully understand the interactive relationships among landscape position, soil erosion, soil nutrient, land use and its history and management.

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