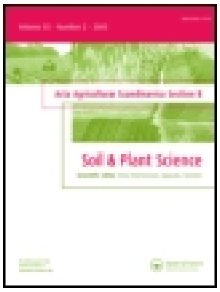

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Spatial variability of soil organic C and total N in a small catchment of the Loess Plateau, China

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ORIGINAL ARTICLE

Spatial variability of soil organic C and total N in a small catchment of the Loess Plateau, China

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Abstract

Data from the Donggou small catchment, located in a typical wind-water erosion crisscross zone on the Loess Plateau of China, illustrate the spatial variability of soil organic carbon (SOC) and total nitrogen (STN) for the 0–0.10 m, 0.10–0.20 m and 0.20–0.40 m soil depths. Statistical analysis revealed that SOC and STN presented moderate spatial variability in the small catchment, and varied with land use. The SOC and STN contents and variations were also influenced by the five land use patterns in a complex manner. Geostatistical analysis showed that Gaussian models were the best fitting descriptors for these SOC and STN data set. The nugget-to-sill ratio ranged from 39.4–56.3% for SOC semivariograms, and 42.6–59.0% for STN semivariograms, indicating moderate spatial dependence at the three soil depths. Regression analysis indicated that land uses, topographic variables, and soil texture accounted for approximately 57.3% of the SOC variability and 70.1% of the STN variability for the 0–0.10 m soil layer. All regression models were reasonable enough to predict SOC and STN in similar loess areas. It was proposed that creating a mosaic pattern to increase spatial variation of areas by land use arrangement would be an effective management strategy to trap soil nutrients to stay in the ecosystem. Our data also suggested that more C input such as manure addition and crop residues return, and alternative cultivation practices such as application of contour cultivation and building terraces for soil erosion control would improve SOC and nutrients on the hilly areas similar to the Loess Plateau of China.

Keywords: *Geostatistics, Loess Plateau of China, regression analysis, soil organic C, spatial variability, statistical analysis, total N.*

Introduction

Recently, much attention has been paid to soil spatial heterogeneity at various scales with the wide applications of GIS and for the development of soil science and landscape ecology. Almost all soil properties exhibit variability as a result of dynamic interactions between natural environmental factors, including climate, parent material, land use, and topography (Jenny, 1941). This variability is likely to impose important consequences on both community structure and ecological processes (Ettema & Wardle, 2002; Gallardo & Paramá, 2007). Soil organic carbon (SOC) and total nitrogen (STN), being two important soil quality indicators, play an important role in alleviating global warming, mitigating land degradation, improving food security, and enhancing crop production (Li et al., 2000; Wang et al., 2001; Lal, 2004; Yimer et al., 2007). Understanding how SOC and STN vary across landscapes is critical for understanding and modelling the operation of ecosystems, and for further controlling soil erosion and improving land management, especially for the Loess Plateau region which is exposed to serious soil degradation (Wang et al., 2003).

Variability of soil properties has been studied extensively (Matheron, 1963; Wang & Gong, 1998; Wang et al., 2003; Dai & Huang, 2006; Liu et al., 2006), and generally the analyses are carried out at the meteorological scale (large areas) and the small catchment scale (small areas). Parent material and

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climate are of major importance in affecting soil variability on regional and continental scales. However, slope gradient, Cos(aspect), relative elevation, soil properties, solar radiation and land use/cover have major influences on the spatio-temporal distribution of soil properties under a hillslope or small catchment scale (Wang et al., 2003; Dai & Huang, 2006). Topography influences soil temperature, runoff and soil erosion, and consequently soil properties, especially soil organic carbon and total nitrogen. On the contrary, variability of soil properties can affect the pattern of crop production, litter formation and its decomposition, which can further feed back on local C and N processes (Wang et al., 2001). Therefore, the variabilities of soil organic carbon and total nitrogen are more intense in complex hills (Miller et al., 1988). Land use is an integrator of several environmental attributes which influence soil variability, and the creation of a mosaic pattern of land use is an effective way to increase soil variability (Wang et al., 2003). On the one hand, land use and soil management practices influence the variability of SOC and STN through the control of organic carbon input and output in the soil system (Fu et al., 2000; Wang et al., 2003). On the other hand, land use influences soil processes, such as erosion, oxidation, mineralization, and leaching, etc., and consequently modifies the processes of transport and re-distribution of SOC and STN (Wang et al., 2001).

The Loess Plateau, cradle of Chinese traditional culture, is characterized by a unique landscape, with very deep loess layers, with a distinct variation in topography, and strongly eroded soils (Fu et al., 2000). Since the 1950s, large activities on soil erosion control and ecosystem restoration have been undertaken by the Chinese government. For small areas, several studies have been reported in the literature differing in the sampling scheme and the methodologies used for assessing spatial variability. Few, if any studies have been directed to the effects of land use pattern on soil organic carbon and total nitrogen variability at various scales.

The objectives of this study were: (1) to analyse the SOC and STN data collected in a small catchment, in order to determine their statistical properties and to investigate their spatial structure also in relation to topography, soil texture, land use and land use pattern; (2) to address the issue concerning the minimum number of point measurements to estimate the mean SOC and STN contents in a given area within a previously established error; and (3) to propose some possible management systems by which the runoff and erosion might be controlled and have SOC and STN might be increased.

Material and methods

Study site description

The experiments were carried out at the Donggou catchment located in the Shenmu County, Shannxi Province, China (38°46′∼38°51′N, 110°21′∼110°23′E), a typical wind-water erosion crisscross zone of the Loess Plateau (Figure 1). The climate in the area is semi-arid temperate with an annual mean precipitation of 430 mm, about 70% of which falls from June to September (Figure 2). The mean annual pan evaporation is 785.4 mm. The soils were developed over wind-accumulated loess parent material, having a sand loam texture. More details about this area can be found in Hu et al. (2008).

Re-vegetation systems in the Donggou catchment consisted of land use mosaic patterns. Major plant species of the cropland (C) were millet in husk [*Setaria italica (L.)Beauv.*], bean (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum L.*), and spring wheat (*Triticum aestivum L.*); in shrubland (S), korshinsk peashrub (*Caragana Korshinskii Kom*); and in orchards (O), apricot (*Prunus armeniaca*). Major species in grassland (A) included bunge needlegrass (*Stipa bungeana Trin.*) and in forage land (B) the legume alfalfa (*Medicago sativa.*). Fallow land (F) included cultivated plots abandoned one year before measurements and they were weeded.

Experimental design

Five sampling spatial transects with a total of 49 sampling locations (Figure 1), each located on one of five down-slope strips of typical land use pattern selected on adjacent hillslopes of the catchment. These patterns from the top to the foot of the hillslope included: pattern M1: land use A-A-A pattern; M2: F-F-C; M3: S-A-C-A; M4: F-S-B-F; and M5: B-C-S (Figure 1). Another group of sampling sites (21 locations), which included orchards, was spread throughout the catchment totaling 70 locations to sample. The main plant species and the number of sampling points on different land uses are shown in Table I.

In October 2007, soil samples of 0–0.10 m, 0.10–0.20 m and 0.20–0.40 m were taken from five points for each site using a 0.20 by 0.05 m soil corer. The five replicate samples were homogenized by hand mixing. Mixed samples of about 1 kg were returned to the laboratory. Major live plant materials (roots and shoots) and stones in each sample were separated by hand and discarded. Soil water content measurements were obtained gravimetrically. The soil samples were air-dried, then passed through 1.0- and 0.25-mm sieves for determination of soil nutrients. SOC was determined by the oil bath-K_2CrO_7 titration

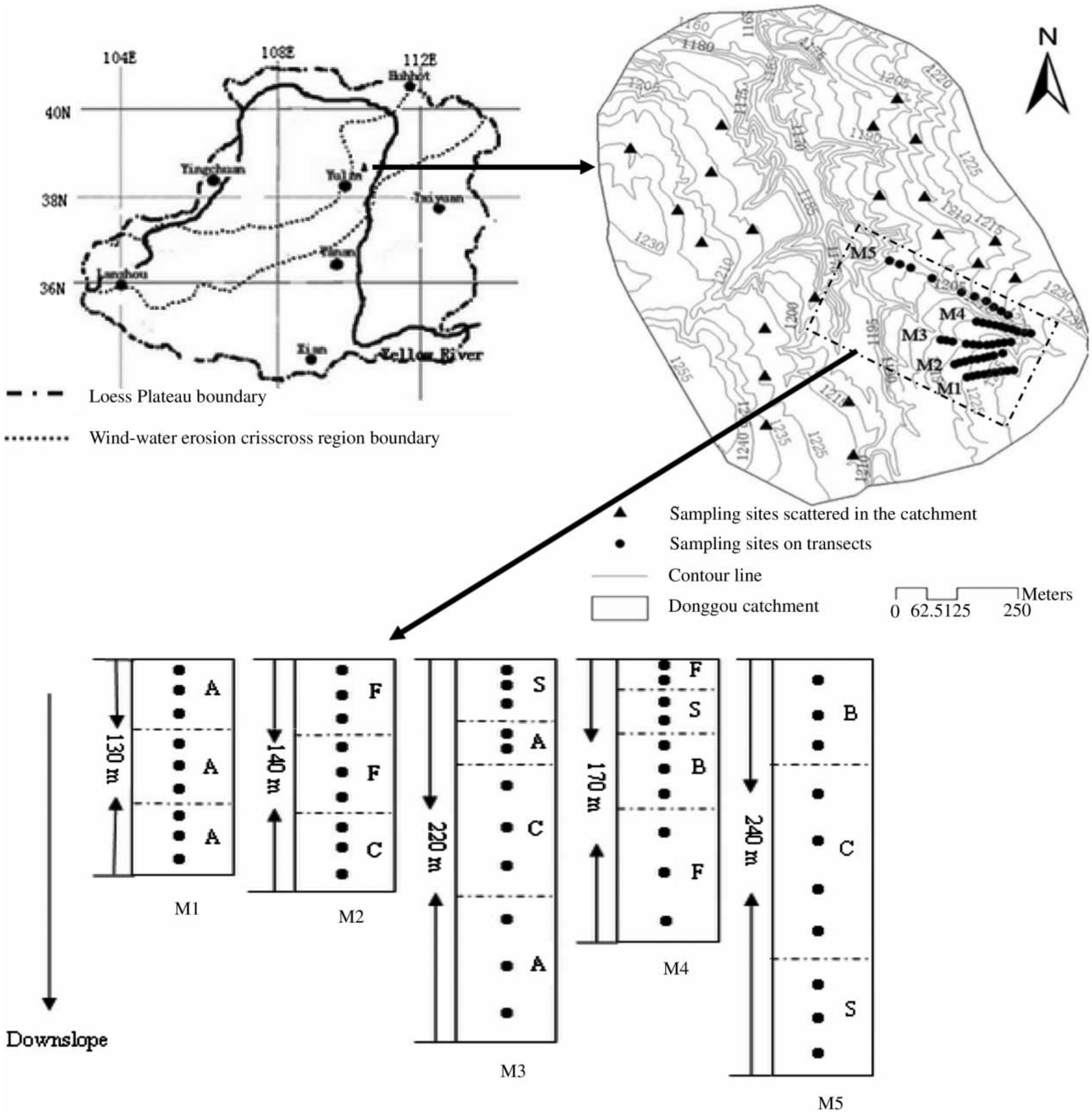

Figure 1. Location of the study area and distribution of sampling sites (M1, M2, M3, M4 and M5 refer to Land use patterns. A, F, C, S, B refer to Grassland, Fallow land, Cropland, Shrubland, and Forage land, respectively).

method. STN was determined by the semi-micro Kjeldahl method. Soil mechanical composition was performed with a MaterSizer2000 laser particle size analyzer manufactured by Malvern. In situ slope inclination and direction were determined by compass. Altitude, longitude, and latitude were determined by portable GPS.

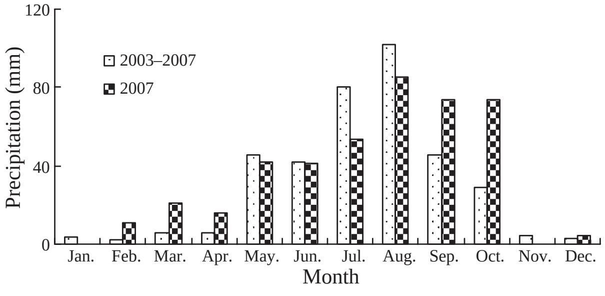

Figure 2. Monthly precipitation distribution in 5-year (2003–2007) mean and experiment year.

Analysis methods

Statistical analyses such as frequency distribution, normality tests, and analysis of variance (ANOVA) were conducted using Microsoft Excel (version 2003) and SPSS (version 13.0). Calculation of experimental variograms and modelling of spatial variability of SOC and STN were carried out with Gstat: a program for geostatistical modelling, prediction and simulation (Edzer, 2001). The relationships between SOC, STN and land use, soil texture, and terrain-based attributes were determined by stepwise regression using SPSS. Land uses (shrub land, orchard, grassland, forage land, fallow land

Table I. Main plant species and number of sampling points in the different land uses.

Land use types	Main plant species	Number of sampling points
Shrubland	Korshinsk Peashrub (*Caragana Korshinskii Kom*)	8
Orchard	Apricot (*Prunus armeniaca*)	3
Grassland	Bunge Needlegrass (*Stipa bungeana Trin.*)	20
Forage land	Alfalfa (*Medicago sativa*)	18
Fallow land	Annual grass	11
Cropland	Millet in husk [*Setaria italica (L.)Beauv.*], Bean (*Phaseolus vulgaris*)	10

and crop land) were transformed into six "dummy" variables (0 for absence and 1 for presence) that can be used as the independent variables. Aspect (clockwise from north), which is a circular variable, was transformed into Cos (aspect). Relative elevation was defined as the elevation deviation from the outlet (1051 m). Slope gradient was recorded as a unit of degree. As consequence, a total of 12 variables (land uses, topographic variables, and soil textures) will be used as the explanatory variables.

Results

Statistical analysis

The one-sample Kolmogorov-Smirnov (K-S) test (a = 0.05 probability level) indicated that the spatial distribution of SOC and STN remained normal for our small catchment. Therefore, no data transformation was performed before statistical analysis. Comparing mean differences with other areas of China (Wang & Gong, 1998; Dai & Huang, 2006), the mean SOC (1.19–3.69 g/kg) and STN (0.19–0.44 g/kg) contents were low for this catchment (Table II). There was a stratification of SOC and STN in the different soil depths. The means decreased significantly with soil depth ($p < 0.05$). Spatial variability of SOC and STN indicated by standard deviation showed a positive trend in relation to soil depths, with strongest variability at surface soil layer (0–0.10 m). When these two indices are combined, the spatial variability indicated by coefficient of variation (CV%) ranged from 17.2% (0–0.10 m) to 24.1% (0.10–0.20 m) for SOC contents, and 16.3% (0–0.10 m) to 19.9% (0.10–0.20 m) for STN contents, indicating a moderate spatial variability ($10\% < CV\% < 100\%$) of SOC and STN (Nielsen & Bouma, 1985), respectively, considering the catchment scale. The coefficients of skewness and kurtosis did not appear to be different from zero throughout all soil depths. Based on normal distribution, the minimum sample size (N_r: number of samplings) required for mean SOC or STN prediction at a given level (k) of accuracy is given as (Hu et al., 2008):

$$N_r = t_a^2 \left(\frac{CV\%}{k}\right)^2 \tag{1}$$

where: t_a is the Student′s **t** for a level of probability α, k can be set from 5–20% depending on the demanded accuracy. Table II shows the number of independent samples required to obtain a value of the field mean SOC and STN contents with $k = 10\%$, at a 95% confidence interval (two-tailed). Obviously, the required sampling size changed with a single-peak curve tendency along soil depths, in this same way as CV% changes. To assess accurately the field mean SOC and STN across the catchment with a precision level of 10%, 11 to 22 sampling points for SOC and 10 to 15 sampling points for STN would be required. Based on that, our sample size (n = 70) was adequate to predict the catchment-mean SOC and STN on all observed soil depths. Considering the differences of sampling numbers required for mean SOC and STN estimation, caution should be taken in using the adequate sample size number to determine SOC and STN values when used for carbon/nitrogen modelling.

Table II. Results of soil organic carbon (SOC), total nitrogen (STN) for descriptive statistics.

	Depths (m)	Mean	Standard Error	Standard Deviation	CV (%)	Skewness	Kurtosis	K-S value	Nr
SOC (g/kg)	0–0.10	3.69	0.075	0.63	17.2	0.29	−0.39	0.66*	11
	0.10–0.20	2.00	0.058	0.48	24.1	0.67	−0.03	0.84*	22
	0.20–0.40	1.19	0.029	0.24	20.1	0.74	0.06	1.18*	15
STN (g/kg)	0–0.10	0.44	0.009	0.07	16.3	0.13	−0.98	0.78*	10
	0.10–0.20	0.28	0.007	0.06	19.9	0.80	0.37	0.82*	15
	0.20–0.40	0.19	0.004	0.03	17.3	0.54	0.18	0.82*	11

K–S value: one-sample Kolmogorov–Smirnov value; *normal with 5% significance level; Nr: minimum sample size required for mean SOC or STN prediction at a given level (10%) of accuracy.

The ANOVA analyses followed the general linear model (GLM) procedure showed that land use and soil depth affected contents of soil organic carbon (SOC), total nitrogen (STN) significantly ($p < 0.05$) (Table III). Among the six land uses, the cultivated lands, consisting of cropland and orchard, had low soil nutrient contents, as has been noted by many authors (Zheng et al., 1996; Wang et al., 2001). The fallow land was established after cropland was abandoned due to increasingly poor yields from the various agricultural crops. Without tillage interruption and organic carbon output from the soil system compared to cultivated lands, the soils of fallow land had a slightly higher mean SOC (2.29 g/kg) and STN (0.31 g/kg) contents, but not significantly, due to the fact that the areas were abandoned for only one year before measurements. The mean SOC and STN contents of 0–0.40 m under forage land were significantly higher than the contents in cultivated lands ($p < 0.05$), which may be due to alfalfa's high yield and more litter and humus returning to soil, as well as its N-fixing characteristic. However, through our investigation in the catchment, we found that the forage land degraded quickly, and it only needed 10 to 15 years for alfalfa land succeeding into the stage of stable prairie community- bunge needlegrass community. With the community composition becoming stable as bunge needlegrass land (grassland), the SOC and STN level also became stable, 2.25 g/kg for SOC, 0.30 g/kg for STN, respectively. Although Shrubland with one kind of leguminous plants that can fix nitrogen, the SOC and STN contents were still lower in this land. On the one hand, Shrub extracted and assimilated lots of nutrients with vigorous growth. On the other hand, the soil texture of the Shrubland is sandier (Table III) with lower ability to retain nutrients.

Figure 3 shows the mean SOC and STN contents at 0–0.40 m soil depths at down-slope positions on the hill slopes of five types of land use patterns. SOC and STN presented an increasing trend from the top to the foot of the hillslope on the M1 (grassland-grassland-grassland) and M2 (fallow land–fallow land–cropland) uniform land use patterns (Figure 3). These distributions were in agreement with the distribution of soil water content on the hillslopes, which could be proved by the positive coefficients of correlation between soil water content and SOC (r = 0.75) and STN (r = 0.67). The uniform or similar land uses along a slope made the entire slope have a similar infiltration rate (Fu et al., 2003) and cause runoff producing areas to be connected, increasing the possibility of wide spread runoff and erosion over the slope. As a consequence, more nutrients were deposited on the foot slope, indicated by the SOC and STN distributions on the hillslopes. The soil nutrient contents of the slope cropland in M2 were higher than in the slope cropland of the other two types. For shrubland-grassland-cropland-grassland (M3), SOC and STN contents presented a wavy shape from the top to the foot of hillslope, with SOC and STN contents of the cropland in middle part being significantly lower than in the upper and lower parts of the slope with grassland (Figure 3). In the land use pattern of fallow land-shrubland-forage land-fallow land (M4) (Figure 3), the contents of SOC and STN were largest in the upper part with fallow land, which significantly higher than that in

Table III. Contents of soil organic carbon (SOC), soil nitrogen (STN), clay, silt and sand in relation to different land uses.

	Depths(m)	Shrub land	Orchard	Grassland	Forage land	Fallow land	Cropland
SOC (g/kg)	0–0.10	3.51(±0.25)bc	2.91(±0.10)c	3.53(±0.09)bc	4.04(±0.06)a	3.85(±0.24)ab	3.57(±0.30)bc
	0.10–0.20	1.79(±0.12)b	2.09(±0.37)ab	1.92(±0.08)b	2.42(±0.09)a	1.90(±0.20)b	1.70(±0.08)b
	0.20–0.40	1.17(±0.07)ab	1.22(±0.07)ab	1.30(±0.07)a	1.11(±0.05)b	1.11(±0.06)b	1.21(±0.04)ab
	Overall	2.15(±0.12)b	2.07(±0.17)b	2.25(±0.06)b	2.52(±0.04)a	2.29(±0.15)ab	2.16(±0.13)b
STN (g/kg)	0–0.10	0.42(±0.02)bc	0.34(±0.02)c	0.42(±0.01)b	0.50(±0.01)a	0.45(±0.02)b	0.43(±0.03)b
	0.10–0.20	0.24(±0.01)b	0.26(±0.03)b	0.27(±0.01)b	0.33(±0.01)a	0.27(±0.01)b	0.25(±0.01)b
	0.20–0.40	0.16(±0.01)b	0.17(±0.02)ab	0.20(±0.01)a	0.20(±0.01)a	0.20(±0.01)a	0.19(±0.01)a
	Overall	0.27(±0.01)bc	0.26(±0.02)c	0.30(±0.01)bc	0.34(±0.01)a	0.31(±0.01)b	0.29(±0.01)bc
Clay (%)	0–0.10	4.15(±0.76)b	5.68(±0.57)a	5.63(±0.24)a	5.22(±0.32)a	5.88(±0.26)a	5.12(±0.28)ab
	0.10–0.20	5.65(±0.95)a	6.22(±0.55)a	7.66(±0.90)a	6.15(±0.76)a	6.35(±0.36)a	6.63(±0.78)a
	0.20–0.40	5.59(±1.08)a	5.41(±0.92)a	6.66(±0.62)a	6.66(±0.50)a	6.82(±0.99)a	8.39(±1.41)a
Silt (%)	0–0.10	43.41(±3.29)c	48.42(±1.30)abc	51.12(±1.62)ab	47.08(±1.56)bc	52.66(±1.67)a	54.34(±1.94)a
	0.10–0.20	50.82(±4.19)b	51.79(±1.99)ab	55.05(±1.37)ab	51.41(±1.94)b	56.25(±1.17)ab	58.51(±1.99)a
	0.20–0.40	49.60(±3.82)b	48.26(±3.53)b	56.52(±1.38)a	56.26(±1.33)a	56.52(±1.43)a	58.69(±1.35)a
Sand (%)	0–0.10	52.45(±4.01)a	45.89(±1.49)abc	43.24(±1.78)bc	47.70(±1.72)ab	41.46(±1.32)c	40.55(±2.18)c
	0.10–0.20	43.53(±5.05)a	41.99(±2.54)a	37.29(±1.98)a	42.44(±2.36)a	37.40(±1.34)a	34.87(±2.57)a
	0.20–0.40	44.81(±4.73)a	46.33(±4.38)a	36.82(±1.78)b	37.08(±1.63)b	36.66(±1.79)b	32.93(±2.57)b

Data represented by mean ± standard error (SE). Means with the same letter across rows are not significantly different ($p = 0.05$) with respect to land uses, respectively at each depth.

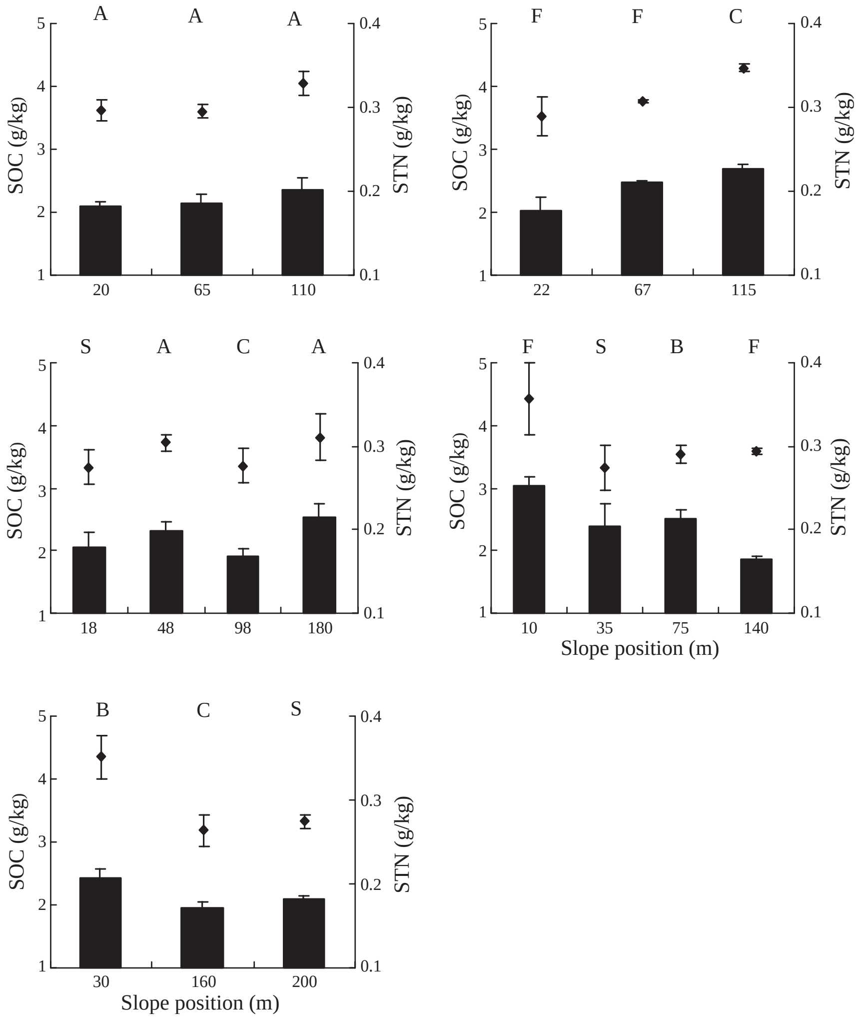

Figure 3. The distribution of mean soil organic carbon (SOC, ■) and total nitrogen (STN, ◆) contents of 0–0.40 m soil depth on five land use patterns (mean ± standard error). (A, F, C, S, B refer to Grassland, Fallow land, Cropland, Shrubland, and Forage land, respectively).

the lower part with fallow land. These differences may be resulted by the fact that the fallow land in the upper part abandoned from terrace cropland had lower soil erosion than that of fallow land in the lower part abandoned from slope cropland. The SOC and STN distributions for forage land-cropland-shrubland (M5) land use pattern presented a "v" shape from the top to the foot of hillslope. Shrubland at the footslope with sandier texture (Table III) had relative low SOC and STN contents, which acted as vegetation strip to absorb the runoff and trap sediments from the upper part of the slope (Fu et al., 2003).

Geostatistical analysis

The semi-variograms for SOC and STN of different soil depths are shown in Figure 4. Key parameters of these fitted semivariograms summarized in Table IV were generated from the Gaussian models, which were the best fitting descriptors for this data set. The semi-variograms of SOC and STN for same soil layer had similar tendencies, and there was a clear spatial structure for both variables in the different soil layers (Figure 4). The nugget for both SOC and STN decreased gradually with increasing soil depth, and all showed positive nugget effect, which can be explained by sampling error, short range variability, random and inherent variability (Liu et al., 2006). Not only random factors, but also structural factors, such as parent material, terrain, and water table, codetermined soil properties (Goovaerts, 1999). The sill value, which is the total system variance included nugget variance and structural variance, also showed decreasing tendencies with increasing soil depth, as the nuggets did. Because nugget and sill were largely influenced by their own factors and by measure unit, there is no meaning to compare nugget and sill values between different variables. However, the ratio of nugget variance to sill variance

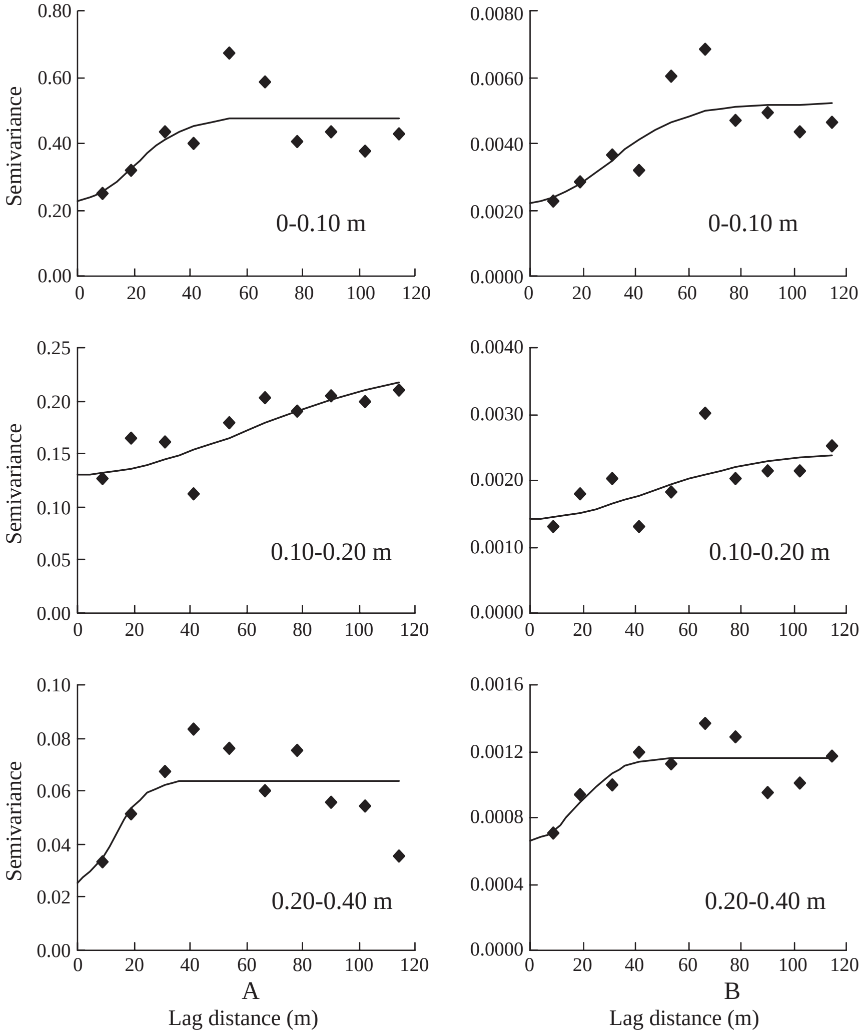

Figure 4. Experimental semi-variograms with fitted models for (A) soil organic carbon (SOC), and (B) total nitrogen (STN) at different soil depths. The light line is the Gaussian model.

expressed as a percentage is an important indication of the spatial dependence of the variable concerned (Wang et al., 2001). Usually, if the ratio is equal or lower than 25%, variables are regarded as strongly dependent; if it is between 25% and 75%, variables are moderately dependent; otherwise, the variable has a weak spatial dependence (Cambardella et al., 1994). In our study, the nugget-to-sill ratio ranged from 39.4–56.3% for SOC semivariograms, and 42.6% to 59.0% for STN semivariograms, indicating moderate spatial dependence. The ranges of spatial autocorrelations were 16–84 m and 24–63 m for SOC and STN, respectively. The greater range at 0.10–0.20 m depth manifested greater localized distances over which each variable is spatially self-correlated within the measured spatial distribution, yet having numerous values at several locations departing markedly from the mean to account for the higher CV at the 10–20 cm depth. So, these spatial dependences may be controlled by intrinsic

Table IV. The parameters of theoretical variogram models for soil organic carbon (SOC) and total nitrogen (STN).

	Depth (m)	Class, model	Nugget	Sill	Nugget/sill (%)	Range (m)
SOC (g/kg)	0–0.10	Gaussian	0.2271	0.4775	47.6	27
	0.10–0.20	Gaussian	0.1311	0.2329	56.3	84
	0.20–0.40	Gaussian	0.0251	0.0636	39.4	16
STN (g/kg)	0–0.10	Gaussian	0.0022	0.0052	42.6	41
	0.10–0.20	Gaussian	0.0014	0.0024	59.0	63
	0.20–0.40	Gaussian	0.0007	0.0012	56.7	24

variations in soil characteristics (texture, mineralogy and soil forming processes) and extrinsic variations (soil fertilization and cultivation practices) (Cambardella et al., 1994; Kiliç et al., 2004).

Regression analysis

The previous analysis revealed different statistical and geostatistical properties of SOC and STN in the small catchment area, indicating that their spatial pattern is possibly influenced by the vegetation cover, soil texture and the within-field variations of topographical attributes. To quantify and clarify these influences, for each soil depth a regression analysis with land use types, soil texture and the topographical attributes was conducted. All the regression models were developed based on the physical relationship between SOC, STN and environmental attributes.

The intercept constants and the regression coefficients of the independent variables for the prediction models of SOC and STN contents at the three soil depths are shown in Table V. The F-value for each regression and the t-test result for each coefficient are also given in Table V. There were different variables entered into regression models at different soil depths, which meant that the variabilities of SOC and STN at different soil depths were controlled by different factors. The positive or negative sign of the regression coefficients of variables reflected the relationship with SOC and STN contents. For example, the coefficients of 0–0.10 m soil depth for orchard were negative since surface soil kept generally lower level of nutrients with this land use in relation to the other types of land use due to strong erosion resulting from the frequently cultivation which disturbed and sparsely covered the soil surface. Forage land with its high aboveground biomass and large N-fixed root system was quite fertile in shallower soil horizons (0.10–0.20 m) owing to the more litter returning to the soil. The regression displayed interesting relationships between SOC, STN and soil texture indices (Table V). For example, SOC of 0.20–0.40 m and STN of 0–0.10 m showed positive relations with clay contents, but STN of 0.10–0.20 m and 0.20–0.40 m presented positive relations with silt contents. The reciprocal relations among environmental attributes had considerable influences on the stepwise regression. In the small catchment, the sand content was not entered into any regression model because it was associated very strongly with the clay and silt contents. In addition, the SOC and STN were also influenced by the terrain attributes. SOC and STN were negatively related to Cos(aspect) and slope gradient, especially in the surface soil layer, implying that the soil nutrient status (SOC and STN) in the north aspect was better than that in the south aspect, as found in other studies (e.g. Wang et al., 2001; Ata Rezaei & Gilkes 2005). Slope has been regarded as one of the most important abiotic factors that control the pedogenic processes on a local scale (Wang et al., 2001; Tsui et al., 2004). Steeper slopes contribute to greater runoff, as well as to greater translocation of surface materials downslope through surface erosion and movement of the soil mass, promoting more nutrient losses. The relative elevation did not contribute significantly to the model of SOC and STN at all the three soil depths.

Regression model for 0–0.10 m layer SOC and STN had the highest adjusted R^2 value, and gradually decreased with increasing soil depth. In 0–0.10 m soil layer, land use, terrain attributes and texture indices together explained 57.3% of the SOC variability and 70.1% of the STN variability, while landscape attributes [slope degree and Cos(aspect)] explained 54.2% of SOC variability and 60.9% of STN variability. This indicated that topography was a dominant factor affecting soil organic carbon and total nitrogen at the surface soil layer. The regression models of SOC and STN were used to calculate predicted values for each land use. A comparison between mean predicted and measured values of SOC and STN of 0–0.40 m soil depths is given by Figure 5. There were no significant differences between the average predicted values in SOC and STN for each land use with their corresponding mean measured values ($p < 0.05$). Thus, our regression models were reasonable enough to predict SOC and STN in similar loess areas.

Discussion

Implications for modelling

These implications for modelling may also have relevance to soil properties estimation in different geographical and climatological regimes. Soil properties such as SOC and STN are state variables which are either simulated or required as input for some soil erosion models. It is necessary to consider all aspects of the regime of the soil properties, such as their level, magnitude of the variability, spatial distribution, and different acting processes when modelling. Usually, the area to be modelled (e.g. for catchment, slope) is subdivided into homogeneous areas with similar soil properties (Flügel, 1995), which are often related to topographic variation or soil type. However, considering the Loess Plateau, the topography and soil textures are varied strongly even in a small catchment like our study area. Regression analysis showed that small scale

Table V. Coefficients of stepwise multiple-linear regression models with spatial attributes (spatial–GM model) developed for the prediction of soil carbon and nitrogen at different depths.

	Depth (m)	Intercept	Shrub land[a]	Orchard[a]	Grassland[a]	Forage land[a]	Fallow land[a]	Crop land[a]	Clay	Silt	Sand	Slope degree	Cos(aspect)	Relative elevation	F
SOC (g/kg)	0–0.10	4.436**	–	−0.600**	–	–	–	–	–	–	–	−0.063**	−0.316**	–	31.8**
	0.10–0.20	2.235**	–	–	–	0.396**	–	–	–	–	–	−0.034**	–	–	19.1**
	0.20–0.40	1.001**	–	–	0.160**	–	–	–	0.021**	–	–	–	–	–	6.5**
STN (g/kg)	0–0.10	0.478**	–	−0.093**	–	–	–	–	0.012**	–	–	−0.009**	−0.031**	–	42.4**
	0.10–0.20	0.212**	–	–	–	0.053**	–	–	–	0.002**	–	−0.005**	–	–	22.3**
	0.20–0.40	0.035	–	–	–	–	–	–	–	0.003**	–	–	–	–	31.6**

(–) Independent variable not entered into the stepwise regression. [a]Binary response (0 for absence and 1 for presence). *Significant ($p = 95\%$) based on the *t*-test. **Significant ($p = 99\%$) based on the *t*–test.

variations in both soil texture and topographic properties control the evolution of SOC and STN variability in the small catchment. Hence, in catchment-scale applications, these various attributes must be incorporated at high resolution into distributed soil erosion models. At the same time, application of multiple land uses on a slope and catchment which increased soil properties variability makes this work more difficult to be carried out. Our results demonstrated that SOC and STN differed significantly among the six land uses (Table III) and that the effects of land use pattern on SOC and STN distribution are complex (Figure 3). Therefore, the homogenous modelling unit with similar soil conditions is not only influenced by the topographical characteristics and soil types, but also by land use and land use patterns.

Implications for sustainable land use management

Comparing the SOC and STN here obtained with other areas in China, their values of our catchment are low. On the Loess Plateau, not only serious soil erosion problems largely account for low soil organic carbon and nutrient levels, but also low C input contributes to this. Therefore, the challenge on how to control soil erosion and improve soil organic carbon and nutrients for plant is a key issue of sustainable land management in this region.

The characterization of soil variability is advantageous in runoff and erosion control (Bergkamp et al., 1996; Fitzjohn et al., 1998). In terms of the ecological value of an area, soil variability may however be beneficial, with distinct soil variations supporting a diversity of ecosystems (Ibanez et al., 1995). This diversity of ecosystems may create a self regulating system in which runoff producing areas are surrounded by buffer zones capable of re-absorbing the product of erosion. Land use change can produce great changes in soil chemical and physical properties, and in turn change in land productivity (Dezzeo et al., 2004). Our results also indicate that SOC and STN contents exhibited moderate spatial variability and significant differences among the six land use systems. The six land uses can be ranked in order of SOC and STN level: forage land > fallow land > grassland > cropland > shrubland > orchard (Table III). This rank series were almost contrary to soil erosion degree in this region, except for shrubland. Mosaic patterns on a slope can be achieved by different land use arrangements (Fu et al., 2003). More nutrients deposited on the foot slope indicated by the SOC and STN distributions on the M1 and M2 uniform land use patterns, meant that more serious soil erosion occurred on the hillslopes with uniform land uses

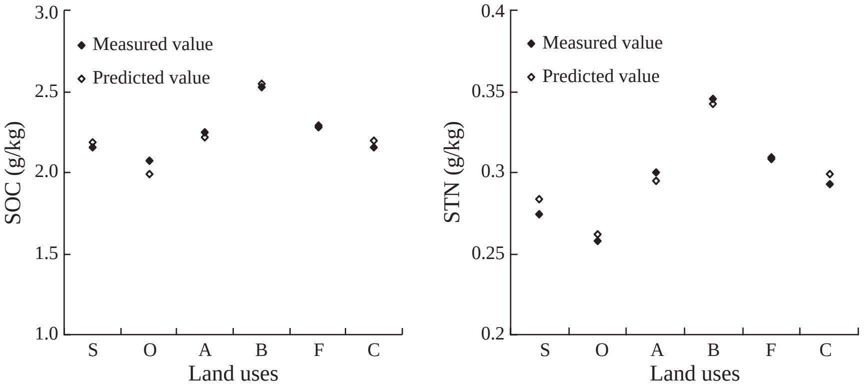

Figure 5. Average predicted and measured values of soil organic carbon (SOC) and total nitrogen (STN) for each land use of 0–0.40 m soil depth. (A, F, C, S, B, O refer to Grassland, Fallow land, Cropland, Shrubland, Forage land and Orchard, respectively).

(Figure 3). To change this situation, land use patterns were developed with spatial arrangement of different land use types (vegetation strips) to absorb the runoff and trap sediments from the upper area, which formed different mosaic patterns of SOC and STN on the slopes, like M3, M4 and M5 land use patterns in our study (Wezel et al., 2000; Fu et al., 2003) (Figure 3). Geostatistical analysis also showed that SOC and STN presented moderate spatial dependence in our catchment, which may be controlled by intrinsic variations in soil characteristics (texture, mineralogy, soil forming processes and terrain characteristics) and extrinsic variations (soil fertilization and cultivation practices). This means that on the Loess Plateau, especially in the wind-water erosion crisscross region, serious soil erosion is a key factor resulting in the low SOC and STN contents, but irrational tillage management and low input of organic manure and chemical fertilizer are also major factors.

Therefore, in terms of runoff and erosion control and improvement of soil organic carbon and total nitrogen, two land management strategies can be derived from above analyses. Firstly, creating a mosaic pattern to increase spatial variation of areas by land use arrangement would be an effective management strategy in runoff and erosion control to trap soil nutrients to stay in the ecosystem. And secondly, more C input such as manure addition and crop residues return to fields would be very useful to ameliorate soil fertility, and alternative cultivation practices such as application of contour cultivation and building terrace for soil erosion control would improve SOC and nutrients on the hilly areas similar to the Loess Plateau of China.

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References

Ata Rezaei, S., & Gilkes, J.R. (2005). The effects of landscape attributes and plant community on soil chemical properties in rangelands. *Geoderma*, *125*, 167–176.

Bergkamp, G., Cammeraat, L.H., & Martinez-fernandez, J. (1996). Water movement and vegetation patterns on shrubland and an abandoned field in two desertification-threatened areas in Spain. *Earth Surface Processes and Landforms*, *21*, 1073–1090.

Cambardella, C.A., Moorman, T.B., Novak, J.M., Parkin, T.B., Karlen, D.L., Turco, R.F., & Konopka, A.E. (1994). Field-scale variability of soil properties in Central Iowa soils. *Soil Science Society of America Journal*, *58*, 1501–1511.

Dai, W.H., & Huang, Y. (2006). Relation of soil organic matter concentration to climate and altitude in zonal soils of China. *Catena*, *65*, 87–94.

Dezzeo, N., Chacón, N., Sanoja, E., & Picón, G. (2004). Changes in soil properties and vegetation characteristics along a forest-savanna gradient in southern Venezuela. *Forest Ecology and Management*, *200*, 183–193.

Edzer, J.P. (2001). Gstat user’s manual. PDF available from: http://www.gstat.org

Ettema, C.H., & Wardle, D.A. (2002). Spatial soil ecology. *Trends in Ecology & Evolution*, *17*, 177–183.

Fitzjohn, C., Ternan, J.L., & Williams, A.G. (1998). Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena*, *32*, 55–70.

Flügel, W.A. (1995). Delineating hydrological response units by geographical information system analyses for regional hydrological modeling using PRMS/MMS in the drainage basin of the river Brol, Germany. *Hydrological Processes*, *9*, 423–436.

Fu, B.J., Chen, L.D., Ma, K.M., Zhou, H. F., & Wang, J. (2000). The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shannxi, China. *Catena*, *39*, 69–78.

Fu, B.J., Wang, J., Chen, L.D., & Qiu, Y. (2003). The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China. *Catena*, *54*, 197–213.

Gallardo, A., & Paramá, R. (2007). Spatial variability of soil elements in two plant communities of NW Spain. *Geoderma*, *139*, 199–208.

Goovaerts, P. (1999). Geostatistics in soil science: State-of-the-art and perspectives. *Geoderma*, *89*, 1–45.

Hu, W., Shao, M.A., Wang, Q.J., & Reichardt, K. (2008). Soil water content temporal-spatial variability of the surface layer of a Loess Plateau hillside in China. *Scientia Agricola*, *65*, 277–289.

Ibanez, J.J., De-alba, S., Bermudez, F.F., & Garcia-alvarez, A. (1995). Pedodiversity: concepts and measures. *Catena*, *24*, 215–232.

Jenny, H. (1941). *Factors of Soil Formation: A System of Quantitative Pedology.* McGraw-Hill, New York.

Kiliç, K., Özgöz, E., & Akbaş, F. (2004). Assessment of spatial variability in penetration resistance as related to some soil physical properties of two fluvents in Turkey. *Soil & Tillage Research*, *76*, 1–11.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, *304*, 1623–1627.

Liu, D.W., Wang, Z.M., Zhang, B., Song, K.S., Li, X.Y., Li, J.P., Li, F., & Duan, H.T. (2006). Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region, Northeast China. *Agriculture Ecosystem & Environment*, *113*, 73–81.

Li, Z.P., Cheng, L.L., & Lin, X.X. (2000). Accumulation of organic matter in infertile red soils and its ecological importance. *Pedosphere*, *10*, 149–158.

Matheron, G. (1963). Principles of geostatistics. *Economic Geology*, *58*, 1246–1266.

Miller, M.P., Singer, M.J., & Nielsen, D.R. (1988). Spatial variability of wheat yield and soil properties on complex hills. *Soil Science Society of America Journal*, *52*, 1133–1141.

Nielsen, D.R., & Bouma, J. (1985). Soil spatial variability. *Pudoc Wageningen*. 2–30.

Tsui, C.C., Chen, Z.S., & Hsieh, C.F. (2004). Relationships between soil properties and slope position in a lowland rain forest of southern Taiwan. *Geoderma*, *123*, 131–142.

Wang, J., Fu, B.J., Qiu, Y., & Chen, L.D. (2001). Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. *Journal of Arid Environments*, *48*, 537–550.

Wang, J., Fu, B.J., Qiu, Y., & Chen, L.D. (2003). Analysis on soil nutrient characteristics for sustainable land use in Danangou catchment of the Loess Plateau, China. *Catena*, *54*, 17–29.

Wang, X.J., & Gong, Z.T. (1998). Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma*, *81*, 339–355.

Wezel, A., Rajot, J.L., & Herbrig, C. (2000). Influence of shrub on soil characteristics and their function in Sahelian agroecosystem in semi-arid Niger. *Journal of Arid Environments*, *44*, 383–398.

Yimer, F., Ledin, S., & Abdelkadir, A. (2007). Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. *Forest Ecology and Management*, *242*, 337–342.

Zheng, J.Y. Wu, R.J. & Zhai, L.N. (1996). Distribution of soil fertility in Zhifang gully watershed of the loess hilly region. *Bulletin of Soil and Water Conservation*, *16*, 26–30. (in Chinese, with English abstract).