Analysis on soil nutrient characteristics for sustainable land use in Danangou catchment of the Loess Plateau, China

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Abstract

Understanding of the characteristics of soil organic matter (SOM) and soil nutrients at the field and catchment scale is important for refining agricultural management practices and for improving sustainable land use. In order to analyze on SOM and nutrient differences among different land use types and their relationships between land use, landscape position and slope aspect, 94 sampling sites including 7 land uses were selected along 6 transects in the Danangou catchment with an area of 3.5 km² on the Loess Plateau of China. Significant differences in SOM, total N (TN), available N (AN) and available P (AP) among these land uses were found. Higher values in SOM, TN and AN were measured in soils from woodland and grassland, but lower values in the soils from fallow land and cropland. Compare SOM and TN with cropland, intercropping land had high contents. The adjusted R^2 values of regression models for SOM and nutrients with land use, landscape position and slope aspect ranged from 0.501 (SOM) to 0.134 (AP). A comparison between average predicted and measured values for SOM and each soil nutrient revealed that the predicted values in TP and AN for each land use, in SOM and TN except for fallow land and in AP except for intercropping land, shrub land and woodland, fell within a 95% confidence interval about the measured values. The simplified predicted models of soil nutrients combined with the key value of SOM for soil quality can serve to improve agricultural practices and to provide useful information on sustainable land use. Improvement in SOM and nutrients would be expected from more C inputs including manure and crop residues and alternative cultivation practices such as developing intercropping system, building terrace for soil and water conservation, return the cropland with SOM content less than a key value of 0.44% to the grassland and woodland on the hilly areas similar to the Loess Plateau of China. At

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the same time, it is recommended that nitrogen fertilization addition could be decreased in the foot slope and increased on the upper slope.

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1. Introduction

Increasing population pressures and a continuous decline in the amount of agricultural land per person have led to an indiscriminate exploitation of natural forests and fragile lands for agriculture (Mahtab and Karim, 1992). However, estimates are that about 40% of agricultural lands are affected by human induced land degradation (Oldeman et al., 1990) such as soil organic matter (SOM) and soil nutrient depletion and other forms of soil degradation. This land degradation in arid, semiarid and dry subhumid areas that results from various factors, including climatic variations and human activities is one of the major issues threatening sustainable land use in drylands (UNCED, 1992; Dumanski and Pieri, 2000), also involving the Loess Plateau of China (Fu et al., 2000). The predominant soil is Calcic Cambisol soil in the Loess Plateau region (FAO-UNESCO, 1988). Despite its importance in food production for the growing population of this area, the soil productivity has still remained low and unstable owing to severe soil erosion with an average $150 \text{ Mg ha}^{-1} \text{ year}^{-1}$ (Chen and Luck, 1989) and continuous decrease in soil nutrients. However, a better understanding of the characteristics of SOM and soil nutrients at the field and catchment scale is important for refining agricultural management practices and for improving sustainable land use (Cambardella et al., 1994).

In order to return to the natural regulating functions of land resources on which sustainability depends, the Chinese government has promoted various policies aiming at returning agricultural land to forestland and grassland. Furthermore, the European Union has also financed a project, “A participatory approach for soil and water conservation planning, integrating soil erosion modeling and land evaluation, to improve the sustainability of land use on the Loess Plateau in northern China—EROCHINA” (Ritsema, *this issue*). During the first phase, the main efforts were devoted to the understanding of gully erosion processes and soil erosion modelling (Wang et al., 2001b; Qiu et al., *this issue*). And then research activities were mainly focused on land evaluation and land use planning to improve the sustainability of land use (Chen et al., 2003). In this paper, SOM and nutrient characteristic analyses including their differences in different land uses and relationships between land use, landscape position and slope aspect were performed. This would help to improve the estimation of SOM and nutrient storage among land uses and agricultural management practices on one hand and to provide useful information on sustainable land use on the other.

The objectives of this study were (1) to assess the effects of land uses on SOM and soil nutrients consisting of total N (TN), TP, available N (AN) and available P (AP); and (2) to establish relationships between SOM and nutrients, and land use, landscape position and slope aspect.

2. Materials and methods

2.1. Study area

The Danangou catchment (36°53'N, 109°19'E) is situated on the middle part of the Loess Plateau in northern Shaanxi province, China. The catchment has an altitude between 1000 and 1350 m with an area of 3.5 km². The region has a semiarid 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 mm (1978) and 297 mm (1974). Sixty percent of the rainfall falls between July and September. There is low soil erosion during the dry season, but very high erosion during the rainy season. Soils developed on wind-deposited loess parent material in the study area, and were classified as Calcic Cambisol soil. The soils are predominantly loess and have a texture of silt ranging from 64% to 73% and clay varying from 17% to 20%.

Land uses comprised cropland, fallow land, grassland, shrub land, orchard land, intercropping land and woodland in the study area (Qiu et al., 2001). Crops were mainly potatoes (*Solanum tuberosum*), beans (*Phaseolus vulgaris*), maize (*Zea mays* L.) and millet (*Panicum miliaceum*). The forest, artificial woods, was dominated by locust trees (*Robinia pseudoacacia* L.). The grassland was mainly covered by annuals such as sweet wormwood (*Artemisia annua* L.), annual fleabane (*Erigeron annuus* Pers.) and sandy needlegrass (*Stipa glareosa* p. Smirn). Littleleaf peashrub (*Caragana microphylla*) and apple trees (*Malus pumila* mill) existed on the shrubland and orchard, respectively. The fallow land slowly came into being two and three years later when cultivated plots were abandoned. There were crops and apple trees on the intercropping land. Fertilizer management for crop included a preplant application of 50 kg/ha as anhydrous NH₃ and 2252 kg/ha of manure (green manure+animal manure) and 20 kg/ha P in middle growing season, but more N fertilizer and manure were added in the orchard (Wang et al., 2001a).

2.2. Soil sampling and measurements

Six transects on which a total of 94 sites were selected for collecting soil samples. Sixty-seven sampling sites distributed at 20-m intervals on the four transects and the others were distributed at 30–50-m intervals along transect (Fig. 1). Based on the six categories of landscape position including upper interfluvial, lower interfluvial, shoulder, upper linear, lower linear and foot slope used by Brubaker et al. (1993, 1994), we divided the hillslope into three positions, upper slope, middle slope and foot slope (Wang et al., 2001a). The upper slope position, relative to upper interfluvial and lower interfluvial, is the uppermost portion of the hillslope. It receives little or no overland flow but may contribute runoff to the downslope position. The middle position consisting of shoulder, upper linear and lower linear receives overland flow from the upper slope and contributes runoff to the foot slope. The foot slope represents the base of the hill. Water and sediment running off the foot slope may enter a waterway or other water conveyance systems.

Fig. 1. Spatial distribution of sampling points in the Danangou catchment.

In July 1999, soil samples of 0–20 cm were taken from five points for each site using a 20 by 5 cm soil corer. The five replicate samples were homogenized by hand mixing. About 1 kg mixed sample was returned to the laboratory at the Ansai Field Station within 7 km of the study site. The soil samples were air-dried, then sieved for the determination of SOM and soil nutrients. Standard soil test procedures for observation and analysis in Chinese ecosystem research network were used (Editorial Committee, 1996). TN was determined by the semi-micro Kjeldahl method, and TP was determined colorimetrically after wet digestion with $\text{H}_2\text{SO}_4 + \text{HClO}_4$ (Parkinson and Allen, 1975). AN was determined by using a micro-diffusion technique after alkaline hydrolysis (Conway, 1978). AP was determined by Olsen method (Emteryd, 1989). Soil organic matter was determined by oil bath- K_2CrO_7 titration method (Nelson and Sommers, 1975).

2.3. Statistical analysis

ANOVA was performed to assess the effects of land uses on SOM and soil nutrients. The relationships between SOM and nutrients, and land use, landscape position and slope aspect were determined by stepwise regression. Independent variables used in this study were land use, landscape position and slope aspect. Land uses were divided into seven classes: fallow land, cropland, intercropping land, orchard, grassland, shrub land and woodland, which were given a numeric value from 1 to 7 in order. Landscape positions consisted of upper slope for value 1, middle slope for 2 and foot slope for 3. Slope aspects included south facing slope for 1, north facing slope for 2 and other aspects for 1.5. The regression models were tested by comparing the estimated values of the five properties with the measured values for each land use. All the statistical analyses were conducted using SPSS program (SPSS Inc., 1993).

3. Results and discussion

3.1. Effects of land use on SOM and soil nutrients

The SOM content variability in the Danangou catchment was low in all the categories: total data (S.D. = 0.217), fallow land (S.D. = 0.019), cropland (S.D. = 0.081), intercropping land (S.D. = 0.094), orchard (S.D. = 0.329), grassland (S.D. = 0.281), shrub land (S.D. = 0.150) and woodland (S.D. = 0.367) (Table 1). There were statistically significant differences among the seven land uses at the 0.01 level. The fallow land was established after cropland was abandoned due to increasingly poor yields from the various agricultural crops. As a result, its soils had the lowest SOM content (0.461%). The soils of cropland (0.467%) were slightly higher SOM content than soils of fallow land, but significantly lower than that of grassland (0.848%) and woodland (1.008%). Compare with the cropland, the soils from intercropping land were high SOM content (0.546%), which implies that intercropping system is a better cultivation practice under the existing management practices and climatic conditions of the study area. More management practices consisting of regular weeding and cultivation activities and more manure addition were given to the orchard because of its high economic values for the local farmers. Therefore, the soils from the orchard had the highest SOM content among the cultivated lands. The highest values for SOM content were found in soils from the grassland and woodland. This result indicates that SOM level would decrease after land use shifts from the woodland and grassland to cultivated land, as has been identified by many authors (Davidson and Ackerman, 1993; Lepsch et al., 1994; Islam and Weil, 2000). In contrast, SOM with other areas of China indicated by Zheng et al. (1996), the mean SOM content (0.549%) for all data, was low in this catchment. This may be attributed to a combination of serious soil erosion and lower C inputs. According to our field investigation of this project team, the amounts of soil loss during rainfall of 1 and 23

Table 1

Mean, standard deviation (S.D.) and ANOVA results of soil organic matter and soil nutrients measured in different land uses

Soil nutrient ^a	SOM		TN		TP		AN		AP	
Land use	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
	(%)		(%)		(%)		(mg/100 g)		(mg/kg)	
All land use	0.549	0.217	0.036	0.011	0.059	0.004	2.910	0.925	1.954	1.532
Fallow land	0.461	0.019	0.031	0.002	0.057	0.003	2.414	0.386	1.332	0.141
Cropland	0.467	0.081	0.032	0.005	0.058	0.004	2.668	0.550	1.966	1.147
Intercropping land	0.546	0.094	0.037	0.006	0.060	0.003	2.956	0.460	2.817	0.695
Orchard	0.750	0.329	0.046	0.019	0.060	0.006	3.170	1.574	3.788	5.817
Grassland	0.848	0.281	0.050	0.014	0.056	0.005	4.110	1.641	1.270	0.198
Shrub land	0.540	0.150	0.035	0.008	0.059	0.002	2.781	0.591	0.970	0.534
Woodland	1.008	0.367	0.058	0.017	0.060	0.004	4.540	1.632	1.314	0.518
<i>F</i> value	18.09**		14.00**		1.20		8.33**		2.82*	

^a SOM = soil organic matter, TN = total N, TP = total P, AN = available N, AP = available P.

* Significant at the 0.05 level.

** Significant at the 0.01 level.

August 1998 were 4128 and 273 kg/hm², respectively, and more runoff occurrence was observed in this year than several previous years (Shi et al., 1999). In addition, according to the results using Participatory Rural Appraisals (PRA) method in the Erochina project (Erochina project report), crop residues like millet and soybean stalks were fed to animals, while maize and sunflower stalks were used as fuel for cooking. So only low amount of residues return to the cropland resulted in low C inputs.

Table 1 showed that TN displayed similar pattern to SOM. This similarity may be related to SOM influencing N retention and supply (Brubaker et al., 1993). Total N content with low variability (S.D. = 0.011 for all data) also showed significant differences among the seven land uses (Table 1). Measurements of TN indicated that the highest content corresponded to soils from noncultivated lands such as the woodland (0.058%) and grassland (0.05%), followed by soils under the orchard (0.046%), intercropping land (0.037%), shrub land (0.035%), cropland (0.032%) and fallow land (0.031%).

Unlike SOM and TN, TP did not show statistically significant differences among land uses. Most of P is held very firmly in crystal lattices of largely insoluble forms, such as various Ca, Fe and AlPO₄s, and also is chemically bonded to the surface of clay minerals (Chen and Zhang, 1991). These may result in relatively small differences in the average values of TP ranging from 0.056% (grassland) to 0.060% (woodland, orchard and intercropping land). Moreover, the variability of TP is very low (S.D. varying between 0.002 and 0.006) in the seven land uses.

Significant differences in AN were detected among the seven land use types at the confidence level of 99% (Table 1). The highest value of AN content (4.540 mg/100 g) was measured in soils under the woodland. This may be due to more litters, porosity and high soil moisture to improve microbial activity. Although additional N fertilizer amount of about 50 kg/ha as anhydrous NH₃ was applied to the cropland, its AN content had a low level. Poorer macroaggregates due to periodical tillage (Islam and Weil, 2000) and less biomass return on harvested land probably account for the lower AN level in the cropland.

The differences in AP content were statistically significant (at the 0.05 level) among the seven land uses. The greatest value in AP, 3.788 mg/kg for soils from the orchard, was almost four times than the lowest value, 0.970 mg/kg for soils of the grassland. A close inspection of Table 1 revealed interesting characteristic of AP, which higher levels tended to occur in the soils under the orchard and on the intercropping land with fruit trees. This pattern of AP may be due to the fact that more mycorrhizal roots in crops especially in leguminous crops compared to apple trees increase the efficiency of P absorption (Pacovsky, 1986; Gnekow and Marschner, 1989).

The soil organic matter reflects the plant residues and soil organisms that have lived and died in the soils. At the same time, its basic functions are the development and maintenance of soil structure, water holding capacity, nutrient and organic carbon storage, and the maintenance of biological activity. Thus, SOM is the best surrogate for soil quality (Dumanski and Pieri, 2000; Murage et al., 2000). As the soil organic matter is consumed and even depleted, it could not sustain economic yields of crops and the cropland was usually abandoned for fallow in order to recover soil fertility. Therefore, SOM on the fallow land may provide critical value, which is considered as having high risk for soil degradation under present climate and management. The critical value is very important for maintaining soil nutrients below which the yields of crops remain very low and

unstable and where the erosional processes may become active, resulting in further soil nutrient depletion and land degradation. In this study, the measured minimum value of SOM for soils from the fallow land was 0.44%, which just had 43.7% and 51.9% SOM of those from the woodland and grassland. Therefore, the SOM value of 0.44% must be considered a key indicator for the abandonment of hilly cultivated land under present management practices and existing climate conditions of the study area. Our results demonstrated that nearly half of the cropland in the catchment had SOM with lower values than this key value. Moreover, these cultivated lands produced poorer yields noted by PRA investigation in our project.

3.2. Relationships between SOM and nutrients, and land use, landscape position and slope aspect

The relationships between SOM and nutrients, and land use, landscape position and slope aspect were given in Table 2. Soil nutrients for which land use, landscape position and slope aspect contributed significantly to the regression model were TP and AN. The slope aspect did not contribute significantly to the model of SOM and TN, whereas the regression model of AP did not include land use. Regression model for SOM had the highest adjusted R^2 value, followed by TN, TP, AN and AP.

Land use and landscape position together explained 50.1% of the SOM variability, while land use itself explained 37.3%. This indicated that land use was a dominant factor affecting soil organic matter. There are identified mechanisms that relate land use and landscape position to SOM. Soil management practices for land use influence soil organic carbon-related soil processes, such as erosion, oxidation, mineralization, leaching and soil respiration (Hontoria et al., 1999). Landscape position plays an important role in several processes such as sedimentation (Kleiss, 1970), soil temperature and erosion (Stone et al., 1985). In turn, these affect soil organic matter accumulation and loss (Pierson and Mulla, 1990).

The regression model of TN including land use and landscape position was similar to SOM, and yet its adjusted R^2 value (0.463) was slightly lower than R^2 of SOM. Land use and landscape position explained 33.0% and 13.3% variability of TN, respectively.

Although the model of TP included significant contribution from three variables, slope aspect explained the highest TP variability (28.0%) among them, but not land use. Land use and landscape position only explained an additional 15.1%. Such a result is a little surprising. This may be explained by the aspect influence on the moisture-heat condition and the topography influence erosion. These feed back differences in soil texture. Good moisture-heat condition of north facing slope would improve biological activity and consequently good soil structure. In addition, in the area of our study, compare with north facing slope, south facing slopes were steeper and shorter to result in more soil erosion and more sand content than that of north facing slopes. Therefore, in the area of this study, differences in soil texture and soil erosion due to slope aspect may obscure the influences of land use and landscape position.

Compare with TN, a distinct difference was that slope aspect entered the regression model of AN. However, it just explained 2.7% variability of AN. The land use and

Table 2
Stepwise regression models of SOM, TN, TP, AN and AP

Soil nutrients ^a	SOM (%)			TN (%)			TP (%)			AN (mg/100 g)			AP (mg/100 g)		
Variables	Coefficient	S.E. ^b	P	Coefficient	S.E.	P	Coefficient	S.E.	P	Coefficient	S.E.	P	Coefficient	S.E.	P
Constant	0.063	0.061	0.305	0.011	0.003	0.001	0.042	0.002	0.000	0.217	0.489	0.659	– 1.527	0.909	0.096
Land use	0.073	0.009	0.000	0.004	0.000	0.000	0.000	0.000	0.034	0.251	0.043	0.000	–	–	–
Position	0.133	0.027	0.000	0.007	0.001	0.000	0.002	0.001	0.000	0.542	0.128	0.000	0.772	0.248	0.002
Aspect	–	–	–	–	–	–	0.006	0.001	0.000	0.476	0.216	0.030	1.073	0.417	0.012
Adjusted R^2	0.501			0.463			0.431			0.371			0.134		
S.E.	0.154			0.008			0.003			0.734			1.425		

(–) Variables not entered the regression model.

^a See Table 1 for abbreviations.

^b Standard error.

landscape position contributed largely to the variability of AN, 22.7% and 11.7%, respectively.

The adjusted R^2 obtained from AP was very low (0.134). Landscape position and slope aspect explained 8.2% and 5.2% variability of AP, respectively. In general, the relatively low amount of AP variability explained may be due to the fact that different state factors are responsible for the accumulation of AP and not all of them were taken into account in this study. Other factors that were not included, such as the degree of erosion, management practices and biological activity, may be responsible for the part remaining of AP variability. Since management practices including tillage and fertilization to influence on biological activity occurred only in the cropland and orchard, P especially for AP was expected to be more differently distributed. In addition, the content of AP was largely dependent on the topsoil erosion. As a result, low amount of AP variability was explained.

The regression models of soil nutrients were used to calculate predicted values for each land use. A comparison between average predicted and measured values of SOM and soil nutrients is given by Fig. 2. The average predicted values in TP and AN for each land use fell within a 95% confidence interval compared with their corresponding measured values. Only an average in SOM and TN for fallow land, and in AP for intercropping land, shrub land and woodland exceeded 95% confidence interval of the average measured value (Fig. 2). Thus, our regression models were reasonable enough to predict SOM and soil nutrients in similar loess areas.

3.3. Implications for sustainable land use

Compare SOM and nutrients with other areas in China, their contents were low. No doubt serious soil erosion largely accounts for this low value (Jiang et al., 1996), but low C input also contributes to this. So, serious erosion and SOM and nutrient depletion are main issues threatening sustainable land use in this area. More attention should pay to control of soil erosion and to improve in SOM and nutrients. Soil organic matter and TN contents exhibited significant differences between in the fallow land and cropland, and in the woodland and grassland. Compare with the cropland and fallow land, the intercropping land had higher values in SOM and TN. The seven land uses can be ranked in order of SOM and TN level: woodland>grassland>orchard>intercropping land>shrub land>cropland>fallow land. The rank series are contrary to soil erosion degree (Zheng et al., 1996). Therefore, several valuable recommendations derived from above analysis. On the one hand, more C input such as manure addition and crop residues return would be very useful to ameliorate soil fertility. On the other hand, alternative cultivation practices such as developing intercropping system, application of contour cultivation and building terrace for soil and water conservation would improve SOM and nutrients on the hilly areas similar to the Loess Plateau of China.

Simplified models for predicting soil nutrients on a given land use, landscape position and slope aspect, when combined with the key value of SOM for soil quality, can be very useful in developing and advancing sustainable land use. If the SOM value for the cropland is lower than the key value, 0.44% in this study area, the cropland should be abandoned for fallow to recover soil fertility. According to the measured SOM content, a value of 0.405% for SOM in the cropland on upper slope position is less than the critical

Fig. 2. Average predicted and measured values of soil organic matter and nutrients for each land use. Vertical bars mark the upper and lower bounds of a 95% confidence interval.

value (0.44%). Because of low economic outputs of crop and high risk for further soil degradation, the cropland must be abandoned for the recovery of soil fertility. However, on upper slope, an organic matter content of 0.634% under the shrub land would be larger than this key value, indicating improvement of soil quality when return the cropland to the shrub land. Moreover, based on the prediction models, land management practices such as fertilizer application could be applied differentially to various landscape positions and slope aspects. In the presence of low N, N fertilizer addition is needed to raise crop yields. On hillslopes where erosion occurs and N is moved downslope, N can be highly variable

along slope. According to our model calculated for TN, TN contents of the upper slope, middle and foot slope are 0.026%, 0.033% and 0.040% in the cropland, respectively. If use of a uniform application of N fertilizer across the slope may be proper fertilization of the middle slope and over-fertilization of foot slope, this would certainly result in unnecessary expense and nitrate contamination into groundwater and surface water due to soil erosion (Emteryd et al., 1998). To reduce unnecessary expense and a loss of valuable nitrogen fertilizer, it is recommended that nitrogen fertilization for the cropland could be decreased in the foot slope and increased on the upper slope. In addition, because runoff and erosion often occur in the rainy season in this area, time of fertilizer addition does not agree with this season.

4. Conclusions

It has been highlighted that soil nutrient depletion and soil erosion are threatening future soil productivity and consequently sustainable land use. Intensive evaluation of SOM and nutrient status was performed in this study. On the one hand, SOM and nutrient contents were low in contrast them with other areas of China. On the other hand, significant differences in SOM, TN, AN and AP among land uses were found. Higher values for SOM, TN and AN were measured in soils from the woodland and grassland, lower values were observed in soils from the fallow land and cropland. Whereas the intercropping land had higher SOM content between cultivated lands. Under present management practices and climatic conditions of the study areas, the SOM value of 0.44% must be considered a key indicator for the abandonment of hilly cultivated land. Below the key value, the soils could not sustain economic yields of crops and had high risk for soil degradation. So, improvement in SOM and nutrients would be expected from more C inputs and alternative cultivation practices such as developing intercropping system and building terrace for soil and water conservation on the hilly areas similar to the Loess Plateau of China.

The adjusted R^2 values of regression models for SOM and nutrients with land use, landscape position and slope aspect ranged from 0.501 (SOM) to 0.134 (AP). The average predicted values in TP and AN for each land use, in SOM and TN except for the fallow land and in AP except for the intercropping land, shrub land and woodland, fell within a 95% confidence interval compared with their corresponding measured values. The approach, simplified predicted models of soil nutrients combined with the key value of SOM for soil quality, can serve to improve agricultural practices and sustainable land use. It is recommended that the SOM content of the cropland less than the key value must return cropland to the grassland and woodland, and that nitrogen fertilization addition could be decreased in the foot slope and increased on the upper slope in order to reduce unnecessary expense and a loss of valuable nitrogen fertilizer.

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