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The effects of land use and its patterns on soil properties in a small catchment of the Loess Plateau

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Abstract: Due to relatively strong human activities in the hilly area of Loess Plateau, the natural vegetation has been destroyed, and landscape pattern based on agricultural land matrix was land use mosaic composing of shrub land, grassland, woodland and orchard. This pattern has an important effect on soil moisture and soil nutrients. The Danangou catchment, a typical small catchment, was selected to study the effects of land use and its patterns on soil moisture and nutrients in this paper. The results are as follows: The comparisons of soil moisture among seven land uses for wet year and dry year were performed: (1) the average of soil moisture content for whole catchment was 12.11% in wet year, while it was 9.37% in dry year; (2) soil moisture among seven land uses was significantly different in dry year, but not in wet year; (3) from wet year to dry year, the profile type of soil moisture changed from decreasing type to fluctuation-type and from fluctuant type to increasing type; (4) the increasing trend in soil moisture from the top to foot of hillslope occurred in simple land use along slope, while complicated distribution of soil moisture was observed in multiple land uses along slope. The relationships between soil nutrients and land uses and landscape positions were analysed: (1) five nutrient contents of soil organic matter (SOM), total N (TN), available N (AN), total P (TP) and available P (AP) in hilly area were lower than that in other areas. SOM content was less than 1%, TN content less than 0.07%, and TP content between 0.05% and 0.06%; (2) SOM and TN contents in woodland, shrub land and grassland were significantly higher than that in fallow land and cropland, and higher level in soil fertility was found in crop-fruit intercropping land among croplands; (3) soil nutrient distribution and responses to landscape positions were variable depending on slope and the location of land use types.

Keywords: hilly area of Loess Plateau; land use pattern; soil moisture; soil nutrient

The hilly area of Loess Plateau of China is the most serious erosion region among the world, and its erosion module is more than 5000 t/(km^2 · a) (Jiang, 1997). Due to fragile ecological environments and strong human activities, natural vegetation has been destroyed, and landscape pattern based on agricultural land matrix was land use mosaic composing of shrub land, grassland, woodland and orchard(Fu, 2000). Land use is an integrator of several environmental attributes that influence nutrients export(Young, 1996). Heterogeneous landscape composed of different land uses affects transpiration and movement of soil moisture and distribution and transfer of soil nutrients(Chen, 2001). In hilly area of loess, soil moisture and nutrients are not only main factors affecting erosion processes, crop growth and vegetation restoration, but one of factors for land evaluation(Fu, 1994). Therefore, most previous studies were conducted about effects of soil moisture on runoff, losing mechanism of soil nutrients, relationships between land use and nutrients lose and effects of soil moisture and nutrients on crop growth and biomass(Chen, 1991; Peng, 1996; Wang, 1999; Liu, 1999). However, there is little information about the effects of landscape patterns composing of land uses on soil moisture and nutrients(Qiu, 2000). Moreover, landscape ecology has paid more attention on an integrated analysis of soil moisture and nutrients in relation to land use and its patterns in heterogeneous landscape(Morris, 1998; Wang, 2001a; 2001b). In this paper, typical Danangou catchment was selected to study on the effects of land use and its patterns on soil moisture and nutrients in hilly area of loess. This analysis would provide insights into effective usage and management of soil moisture and nutrients, and would be helpful to understand the relationships between pattern and process on landscape scale.

1 Study area

The Danangou catchment (109°16′ - 109°18′E, 36°54′ - 36°56′N) is situated near the centre of the Loess Plateau in northern Shaanxi Province, China. The catchment has an area of 3.5 km^2 and an altitude of 1000—1350m. The average annual precipitation is 549 mm with great interannual variability, and 60 percent of the rainfall falls between July and September. There are significant topographic variations with typical loess hills and gully landforms within the study area. The predominant soil in the study area is loess and has a texture of silt ranging from 64% to 73% and clay varying from 17% to 20%. It is weekly resistant to erosion. Prolonged human activities have destroyed all the natural vegetation, and the land uses were a mosaic of slope cropland, fallow land, grassland, shrub land, intercropping land and woodland.

2 Methods

Based on characteristics of land use, topography and soil, typical land use patterns, cropland-cropland-cropland, cropland-woodland-orchard, fallow land-grassland-cropland-cropland, shrub land-intercropping land-woodland, fallow land-cropland-woodland-orchard (slope 1), fallow land-shrub land-cropland-woodland-orchard(slope 2) and intercropping land-woodland(slope 3) were selected(slope 1, slope 2 and slope 3 were analyzed for effects of landscape position on soil nutrients). Total 26 and 81 sampling points for measuring soil moisture were established in 1998 and 1999, respectively, while 33 sampling points for collecting soil sample of nutrients.

Soil moisture was measured at intervals of approximately two weeks from May to October in 1998 and 1999 using a Theta Probe Soil Moisture Sensor Type ML1 (Delta-T Devices, Eijkelkamp Agrisearch Equipment, The Netherlands). Total 20 measurements for 10 times of each year were performed. Moisture was measured at five depths: 0—5 cm, 10—15 cm, 20—25 cm, 40—45 cm and 70—75 cm. Mean soil moisture contents were calculated for each depth and for the whole profile at each site.

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In August and October 1998 and July 1999, surface soils were collected for the same 33 sites respectively. Samples of 0—20 cm depth were taken from five random locations within a 2m diameter circle around each point using a 20 by 5 cm soil corer. The five replicate samples were homogenized by hand mixing. About 1 kg mixed samples was returned to the laboratory. The soil samples were air-dried, then passed through 1.0 mm and 0.25 mm sieves for determination of soil nutrients. Methods of five soil nutrients test were SOM for oil bath-K_2CrO_7 titration method, TN for the semi-micro Kjeldahl method, TP for colorimetrically after wet digestion with H_2SO_4 + $HClO_4$, AN for a micro-diffusion technique after alkaline hydrolysis and AP for Olsen method.

Average in rainfall was recorded by five automatic datalogged rain gauges located in the catchment. The year of 1998 with a rainfall of 629.62 mm during observation period was wet year, while the year of 1999 with a rainfall of 224.48 mm was dry year.

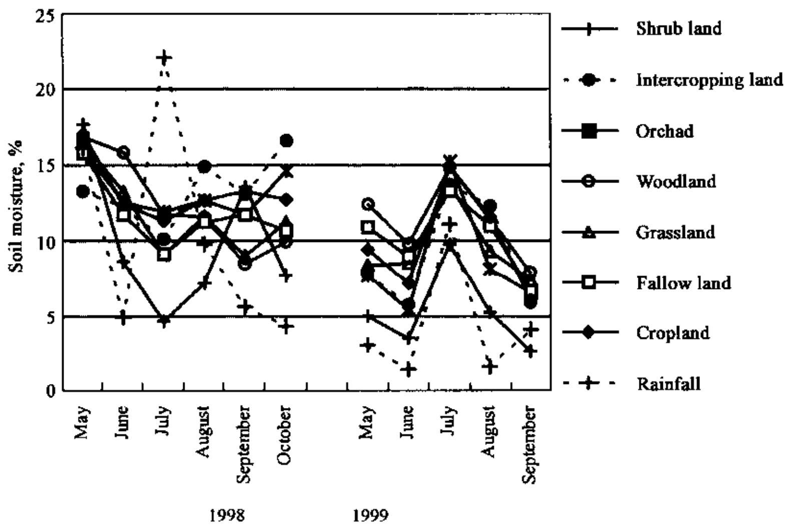

Fig.1 Seasonal evolution of 0—70 cm soil moisture between wet year and dry year

3 Results and analysis

3.1 Land use and soil moisture

3.1.1 Comparison of mean soil moisture of 0—70 cm between wet year and dry year

Fig. 1 shows seasonal evolution of 0—70 cm soil moisture between wet year and dry year. The seasonal changes in soil moisture were closely related to rainfall. Wet and dry patterns of soil moisture were not clear during wet year because of more than 100 mm rainfall at the beginning of growth period and subsequent average in 40 mm each month highly compensating for soil moisture loss. However, wet pattern before dry pattern existed in dry year, because little rain was not in favor of accumulation of soil moisture. Therefore, these results indicated that the amount of rainfall and its distribution during growth period was a dominant factor affecting seasonal changes of soil moisture, and that great and little rainfall previous year has effect on soil moisture.

Soil moisture contents for all land uses in wet year were higher than that in dry year (Table 1). Differences in soil moisture for shrub land, intercropping land and orchard in wet year and dry year more than 4% were larger than that for woodland and fallow land less than 1%. Average in soil moisture of the catchment was 12.11% in wet year and 9.37% in dry year, respectively.

Table 1 Averaged soil moisture contents of seven land use types during wet and dry years. Values in each row with the same letter are not significantly (α = 0.05) different among land uses

Year	Soil moisture content, %								
	Shrub land	Intercropping land	Orchard	Woodland	Grassland	Fallow land	Cropland	Mean	F values
1998	9.67a	13.71a	13.12a	12.02a	11.6a	11.57a	13.08a	12.11	1.92
1999	5.49a	9.31b	8.74ab	11.74b	9.56ab	10.6b	10.17b	9.37	6.02**

Notes: ** significant difference at level α = 0.01

Significant differences in soil moisture among land uses were observed in dry year, but not in wet year, and multiple comparisons showed moisture content of shrub land was lower than other that of land uses (Table 1). This indicated that differences between land uses decreased in wet year.

3.1.2 Comparison of profile soil moisture between wet year and dry year

Fig.2 exhibits types of profile soil moisture for wet year and dry year. In wet year, profile soil moisture showed decreasing type for shrub land, increasing type for fallow land, cropland, intercropping land and grassland, and fluctuant type for woodland and orchard. However, in dry year, fluctuant type was found in shrub land, increasing type existed in other six land uses. Therefore, types for profile soil moisture changed from decreasing type to fluctuant type, from fluctuant type to increasing type when dry year followed wet year.

3.1.3 Effects of land use patterns on soil moisture in wet and dry years

Whether wet year or dry year, soil moisture for single land use pattern increased from the top to foot of slope. However, soil moisture distribution along slope exhibited complicated pattern in multiple land use structure. Moreover, moisture content was related to the location of land use in slope. For example, moisture content of woodland in middle slope was less than that in upper and foot slope in wet year, but this pattern did not occurred when woodland situated in foot slope (Wang, 2000a). Moreover, moisture exhibited similar pattern in dry year when woodland located in foot slope. In addition, the observations from consecutive two years discovered that occurrence of the rain affected moisture distribution along slope and mitigated the difference in moisture from the top to foot of slope, and that the drought decreased difference in surface soil moisture, increased difference in soil moisture in deep depth and disturbed moisture distribution along slope (Wang, 2000b).

3.2 Land use and soil nutrients

3.2.1 Comparison of soil nutrients between land uses

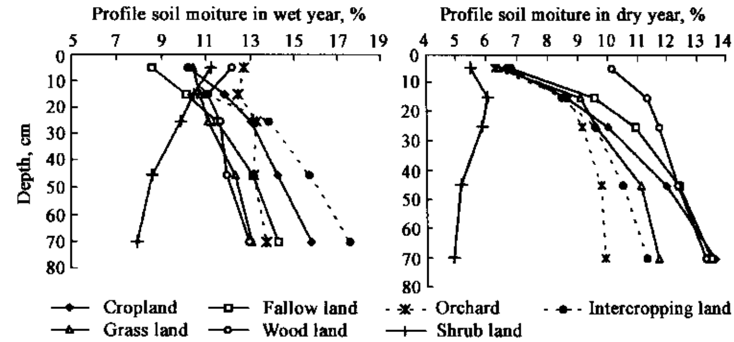

Fig.2 Types of profile soil moisture of seven land uses during wet and dry years

Seasonal averages in soil nutrients of noncultivated lands including fallow land, woodland, shrub land and grassland, and cultivated lands composing of cropland, orchard and intercropping land showed significant differences in SOM, TN, AN and AP (Table 2). The higher SOM, TN and AN contents were found in noncultivated lands than those under cultivated lands. Their highest values occurred in woodland, shrub land and grassland. The results indicate that cultivation decreases soil nutrient levels, as has been indicated by many authors(Davidson, 1993; Lepsch, 1994). Significant differences in SOM, TN and AN among the seven land use types were found(Table 2). The mean SOM content varied between 0.492% and 0.883%. Its multiple comparisons revealed that SOM level under woodland, shrub land and grassland was significantly higher compared to fallow land and cropland. TN content (0.029%—0.051%) and AN(2.617—4.055 mg/100g) displayed similar patterns to SOM for multiple comparisons. This similarity may be related to SOM influencing nitrogen retention and supply(Brubaker, 1993; 1994). Mean TP content did not show statistical difference among land uses because of its stability in soil(Chen, 1996). Although AP for seven land use types was not statistically significant(Table 2), high values tended to occur in orchard and intercropping land with fruit trees. This may be due to that fruit trees need less P element during growing season comparison with other plants.

3.2.2 Effects of landscape position on soil nutrients

The effects of landscape position on soil nutrients depended on slope. There were no significant differences in soil nutrients among landscape positions on slope 1. Close observation suggests that there is a tendency for greater values in nutrients at the position of middle slope. Higher nutrients mean less nutrient lose through runoff in hilly area of loess with serious erosion. Due to woodland in middle slope, it decreased occurrence of runoff and deposited part of nutrients from upper slope.

Land use types of slope 2 were much different than that of slope 1. 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 July revealed that SOM, TN, TP, AN and AP contents on foot slope were significantly higher than those on upper slope and middle slope. The lowest levels in TN, AN and AP occurred on the upper slope position. Although differences for most of nutrients among landscape positions 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.

Table 2 Average in soil nutrients for seven land use types, values in each column with the same letter are not significantly (α = 0.05, LSD) different among land uses

	SOM, %	TN, %	TP, %	AN, mg/100g	AP, mg/kg
Noncultivated land use	0.790	0.045	0.060	3.669	1.153
Cultivated land use	0.544	0.034	0.060	2.730	2.291
F value	14.859**	10.367**	0.516	10.272**	4.571*
Land use					
Fallow land	0.492a	0.029a	0.058a	2.617ac	1.172a
Cropland	0.515a	0.033a	0.059a	2.626a	1.748a
Orchard	0.628ac	0.038ac	0.061a	2.777ac	3.348a
Woodland	0.865b	0.051bcd	0.062a	3.931bd	1.173a
Shrub land	0.883bcd	0.049bce	0.060a	4.055cd	1.193a
Intercropping land	0.546ade	0.037ade	0.063a	3.081ad	3.057a
Grassland	0.881bce	0.050bce	0.059a	3.942cd	1.010a
F value	4.448**	3.732**	0.960	2.974*	2.054

Notes: * and ** Significant at the 0.05 and 0.01 level, respectively

In contrast to slope 1 and slope 2, slope 3 had the simplest land use structure. There was similar trend in soil nutrients to slope 2. Most of nutrients tended to the higher levels on foot slope and the lower levels on upper position. Larger pronounce 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 upper position.

4 Discussion and conclusions

Based on soil moisture data collected in Danangou catchment during consecutive two years, the effects of land use and its patterns on soil moisture were analysed. The conclusions as follows: (1) the amount of rainfall and its distribution during growing period was a dominant factor affecting seasonal changes of soil moisture, great and little rainfall in previous year has also effect on soil moisture; (2) soil moisture among seven land uses was significantly different in dry year, but not in wet year; (3) when dry year followed wet year, the profile types of soil moisture changed from decreasing type to fluctuant type and from fluctuant type to increasing type. The decreasing type and increasing type have different significances in ecology and hydrology. The decreasing type has a stable layer of low moisture to restrict plant growth, but increasing type can compensate for loss of surface soil moisture in favor of plant growing. However, in view of hydrological significance, decreasing type would be helpful for water infiltrating soil to mitigate occurrence of runoff. It is important to cope with their relationships in this region; (4) the increasing trend in soil moisture from the top to foot of slope occurred in simple land use along slope, while complicated distribution of soil moisture was observed in multiple land uses along slope. This implicated that adjustment of soil moisture pattern through spatial arrangement of land uses would decrease erosion.

According to soil nutrient data in Danangou catchment, the relationships between soil nutrient and land use and landscape position were explored. The results were: (1) five nutrients with lower content in hilly area of loess compared with other areas, SOM was less than 1%, TN content less than 0.07%, and TP content between 0.05% and 0.06%. This implicated that serious erosion resulted in a large amount of nutrient loss; (2) SOM and TN contents in woodland, shrub land and grassland were significantly higher than that in fallow land and cropland, and higher level in soil fertility was occurred in crop-fruit intercropping land among farmlands. In order to improve soil fertility in this area, it is important to regulate present irrational land use patterns except for developing multiple intercropping systems and building works for soil and water conservation; (3) soil nutrient distribution and responses to landscape positions were variable depending on slope and the location of land use.

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