Journal of Geographical Sciences 15, 4 (2005) 396–404 ISSN: 1009–637X www.geog.cn

The effects of land use on runoff and soil nutrient losses in a gully catchment of the hilly areas: implications for erosion control

WANG Jun[1,2], *FU Bojie*[3], *QIU Yang*[1], *CHEN Liding*[3], *CHEN Chen*[4], *HU Baodong*[5]
(1. Beijing Normal University, Beijing 100875, China; 2. Land Consolidation and Rehabilitation Center, the Ministry of Land and Resources, Beijing 100035, China; 3. Research Center for Eco-Environmental Sciences, CAS, Beijing 100085, China; 4. Portland State University, Oregon 97201, USA; 5. Zhengzhou Riverway Administration Department, Zhengzhou 450000, China)

Abstract: Serious soil erosion is one of the major issues threatening sustainable land use in semiarid areas, especially in the Loess Plateau of China. Understanding the effects of land use on soil and water loss is important for sustainable land use strategy. Two sub-catchments: catchment A (CA) and catchment B (CB) with distinct land uses were selected to measure soil moisture, runoff and soil nutrient loss in Da Nangou catchment of the Loess Plateau of China. The effects of land use patterns on runoff and nutrient losses were analyzed based on soil moisture pattern by kriging and soil nutrients using multiple regression model. The results indicated that there were significant differences in runoff yield and soil nutrient losses between the two sub-catchments. With similar land uses, the CA produced an average sediment yield of 49 kg ha^{-1} and 22.27 kg ha^{-1} during two storm events. Meanwhile, there was almost no runoff in the CB with dissimilar land uses during the same events. Buffer zones should be established to re-absorb runoff and to trap sediments in catchment with similar land use structure such as the CA. Moreover, land use management strategy aiming to increase the infiltration threshold of hydrological response units could decrease the frequency of runoff occurrence on a slope and catchment scale.

Key words: soil erosion; runoff; soil nutrient; land use pattern; the Loess Plateau of China
doi: 10.1360/gs050402

1 Introduction

Soil and water loss is one of the worldwide environmental issues threatening sustainable land use in semiarid areas. However, soil and water loss is highly variable in space and time, and its variability results from many factors operating at a wide range of scales influenced by soils, land use, topography and rainfall (Bissonnais *et al*., 1998; Rai and Sharma, 1998; Deidda, 2000). In order to better control soil and water loss, it is necessary to understand the spatio-temporal variability of soil erosion under different climatic and geological conditions and at different hierarchical space scales and timescales.

Land use is an integrator of several environmental attributes which influence nutrients export (Young *et al*., 1996), and also plays an important role in affecting spatial patterns of soil erosion (Reynolds, 1970; Ng and Miller, 1980; Francis *et al*., 1986; Fu and Gulinck, 1994; Fu *et al*., 2000). Many studies were conducted for the effects of land use on soil erosion in temperate and tropical regions associated with weak soil erosion (Phillips, 1992; Bissonnais *et al*., 1998; Boix-Fayos *et al*., 1998; Rai and Sharma, 1998). More and more attentions on soil erosion are paid to the Loess Plateau of China. Because the Loess Plateau has been suffering from serious soil erosion with an average 150 Mg ha^{-1} yr^{-1} (Chen and Luck, 1989) that has resulted in an

---

Received: 2005-02-18 **Accepted:** 2005-05-10

Foundation: National Natural Science Foundation of China, No.40401001; No.40201003; Programme of Excellent Young Scientists of the Ministry of Land and Resources

Author: Wang Jun (1970-), Ph.D. and Associate Professor, specialized in landscape ecology and sustainable land use.
E-mail: wangjun@lcrc.org.cn

enormous loss of fertile surface soil and further land degradation (Wang *et al*., 2003). The most important reason for soil erosion is irrational land use and low vegetation coverage (Fu and Gulinck, 1994; Jiang, 1997). Therefore, it is very helpful to explore the land use affecting soil and nutrient losses for erosion control in this area.

There is a runoff-producing mechanism of rain intensity exceeding soil infiltration capacity in the Loess Plateau (Li *et al*., 1995; Liu and Kang, 1999). Soil infiltration capacity and land cover are two major factors affecting runoff and soil erosion processes. Land use (vegetation) determines the land cover characteristics while soil moisture and soil physical properties greatly affect infiltration capacity (Bárdossy and Lehmann, 1998). Without information on soil moisture variability, prediction and interpretation in catchment hydrology will be problematic (Phillips, 1992). Since soil moisture is a function of the soil physical and hydraulic properties (Reynolds, 1970; Nielsen *et al*., 1973), the spatial pattern of soil moisture combined with land use may be used to identify contrasting areas of hydrological response and hence, the spatial arrangement of runoff-producing areas (Fitzjohn *et al*., 1998).

The objectives of this study are: (1) to analyze the effects of land use patterns on runoff and soil nutrient losses based on spatial pattern of soil moisture by kriging and soil nutrients by multiple regression in a small catchment of the Loess Plateau of China; and (2) to discuss the implications for land use management strategies targeting soil erosion control.

2 Materials and methods

2.1 Study area

The Da Nangou catchment (36°53'N, 109°19'E) is situated in the middle part of the Loess Plateau in northern Shaanxi province, China. The catchment has an altitude between 1000-1350 m with an area of 3.5 km^2. The region has a semiarid continental climate with an average year-round temperature of 8.8 ℃. Monthly mean temperature ranges from 22.5 ℃ in July to -7 ℃ in January. The average annual precipitation is 562 mm with the maximum and minimum recorded values of 645 mm (1978) and 297 mm (1974) respectively. Sixty percent of the rainfall occurs between July and September. Soil developed on wind-deposited loess parent material in the study area is classified as Calcic Cambisol soil.

At present, land use types consists of slope cropland, fallow land, grassland, shrubland, orchard land and woodland in the study area (Figure 1). Four adjacent slopes spreading over two sub-catchments, namely catchment A (CA) and catchment B (CB), were selected. The CA, with an area of 14.25 ha, was composed of cropland (76%), grassland (22%) and shrubland (2%). The area of the CB was 7.76 ha. Its land use structure consisted of cropland (37%), fallow land (5%), shrub land (10%), intercropping land (43%) and woodland (5%).

2.2 Soil moisture and nutrient measurements

The CA and the CB giving 67 sampling points at an interval of 20 m and additional 28 points, a total of 95 points were selected to determine soil moisture and nutrients (Figure 2). Soil moisture was measured using a Theta-Probe Soil Moisture Sensor Type ML1 (Delta-T Devices, Eijkelkamp Agrisearch Equipment, the Netherlands). It was measured at an interval of approximately two weeks from May to September 1999, as well as every second or third day following all major rain events. After augering to the measuring depth, four parallel steel rods (length 6 cm, diameter 0.3 cm, and spacing 2.5-3 cm) were inserted vertically into the soil, and remained in position until the displayed value of the Theta Probe stabilized. Moisture was measured at five depths: 0-5 cm, 15-20 cm, 25-30 cm, 45-50 cm and 70-75 cm. Mean soil moisture contents over the 5 depths were calculated for each site on every occasion. Spatial patterns of soil moisture before runoff occurrence were described by using kriging interpolation (Wang *et al*., 2001; 2002). Average precipitation was recorded by five automatic datalogged raingauges located in the catchment.

Soil samples of 0-20 cm were taken from each site using a 20 by 5 cm soil corer in July

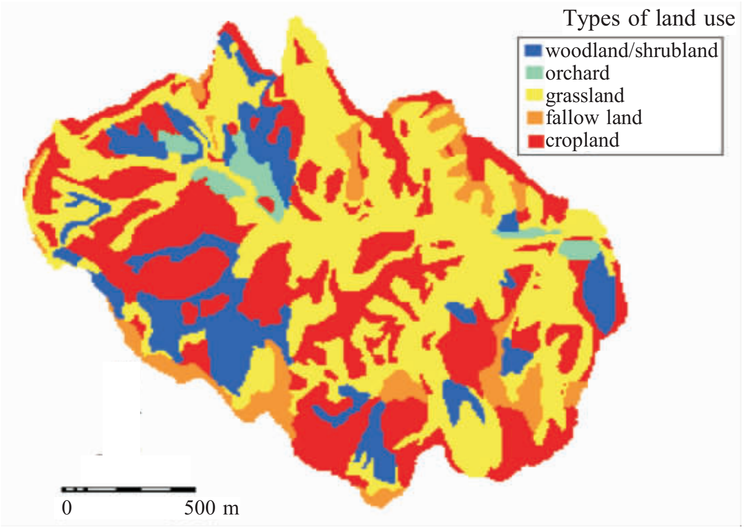

Figure 1 Land use types of the Da Nangou catchment

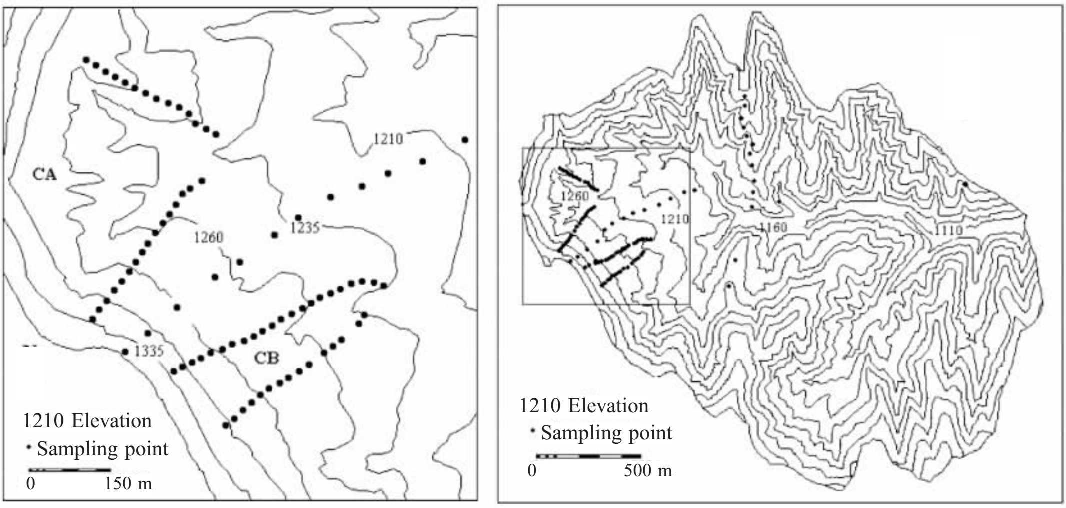

Figure 2 Spatial distribution of sampling points in the Da Nangou catchment (CA: the catchment A; CB: the catchment B)

1999. These soil samples were air-dried, then passed through 1.0 mm 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). Total nitrogen (TN) was determined with the semi-micro Kjeldahl method, and total phosphorus (TP) was determined colorimetrically after wet digestion with H_2SO_4+$HClO_4$ (Parkinson and Allen, 1975). Available nitrogen (AN) was determined by using a micro-diffusion technique after alkaline hydrolysis (Conway 1978). Available phosphorus (AP) was determined with Olsen method, and soil organic matter (SOM) was determined by oil bath-K_2CrO_7 titration method (Emteryd, 1989). The spatial pattern of SOM, TN, TP, AN and AP were estimated using multiple regression considering on land use types and topographical factors (Qiu, 2001) (Figure 3).

2.3 Calculation of runoff amounts and sediment yield

Two dams were built at the outlet of each catchment. Runoff amounts were calculated by runoff

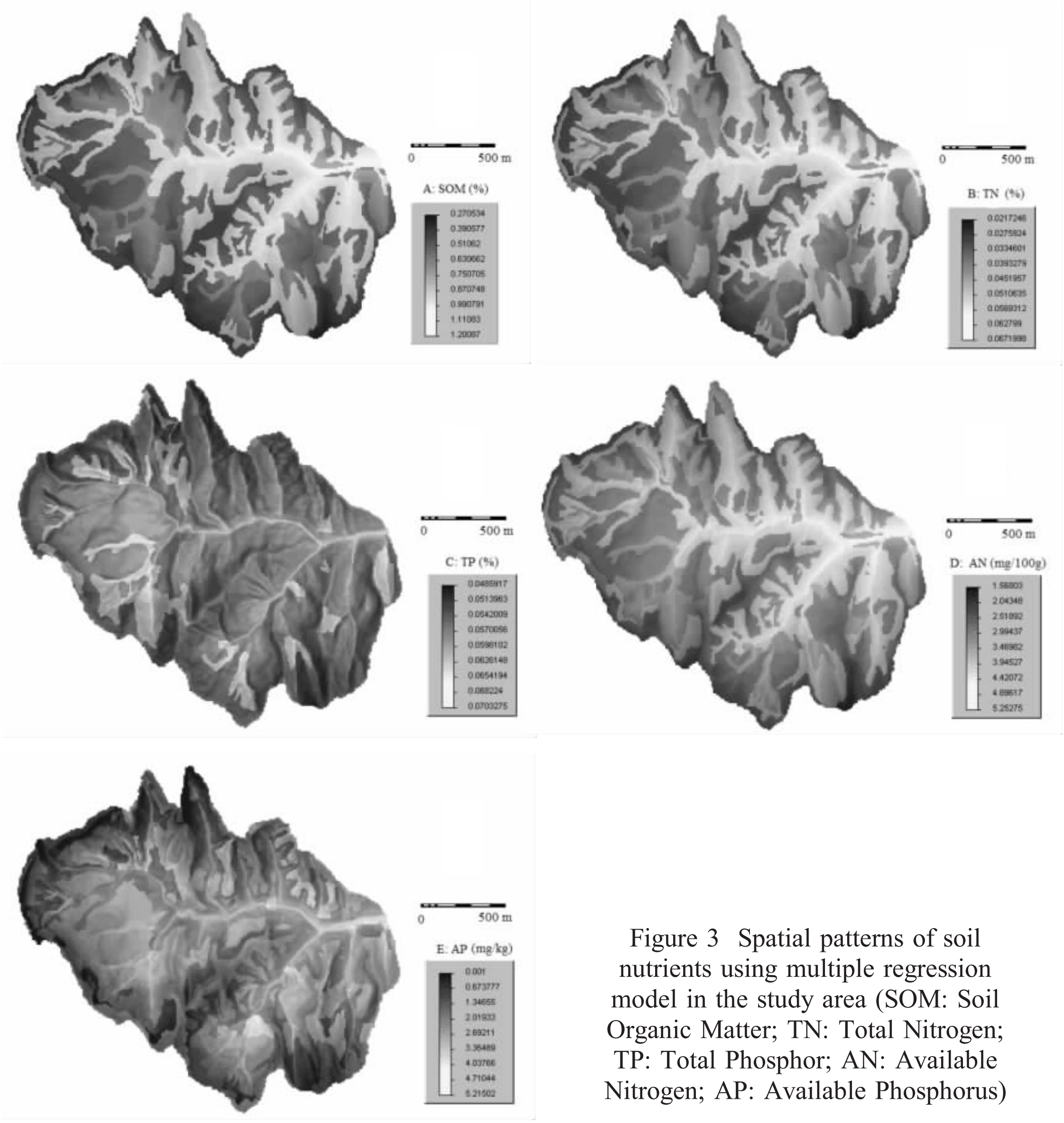

Figure 3 Spatial patterns of soil nutrients using multiple regression model in the study area (SOM: Soil Organic Matter; TN: Total Nitrogen; TP: Total Phosphor; AN: Available Nitrogen; AP: Available Phosphorus)

curve after water level and speed were determined. The collected runoff samples were measured by volumetric cylinder glass, and then air-dried to determine sediment weight. The sediment yield was computed as the ratio of the mass of sediment (kg) to the area of the catchment (ha).

3 Results

3.1 Land use pattern and runoff amounts

Differences existed in runoff amounts and sediment yield between the CA and the CB during the two rain events (Table 1). Runoff occurred at the CA during both events, but not at the CB. The average sediment yield was 49 kg ha^{-1} in the CA on 10 July when the rainfall lasted 28 minutes and the total precipitation reached 10.64 mm. During the second rainfall on July 20, the CA produced a sediment yield of 22.27 kg ha^{-1}. The second rainfall lasted 44 minutes and the precipitation was 16.15 mm. The different runoff amounts between the CA and the CB may be attributed to a combination of differences in soil moisture, plant coverage and soil physical properties (Qiu *et al.*, 2003). According to our investigation and analysis, cultivated land with similar plant coverage and soil physical properties occupied 67% of the total land in the CA. Its soil moisture exhibited an increase from the top to the footslope. However, different types of land use resulted in significant differences in soil moisture along the slope in the CB (Wang *et al.*, 2001; 2002). During the rainfall event, high heterogeneity of soil moisture and physical properties may produce differences in infiltration rate. This would result in unconnected runoff-producing areas and would decrease the possibility of runoff occurrence on the whole slope. Just as other scientists indicated that high land use diversity dispersed the risk of soil erosion to prevent from the larger erosion happening (Ludwig *et al.*, 1999; Rai and Sharma, 1998). Compared with the CA, the CB could decrease 71.27 kg ha^{-1} of soil loss under similar rain conditions.

3.2 Differences in soil nutrient contents between sediment and surface soil

Soil nutrients experience two kinds of losses during water erosion process. One is the loss accompanying soil loss, and the other is dissolved loss in runoff (Liu *et al.*, 1995). Many studies have indicated that the main model of soil nutrient loss is related to soil loss in the Loess Plateau (Chen and Zhang, 1991; Wang and Liu, 1999). Table 2 shows the differences in soil nutrients between the sediment and surface soil in the CA and the CB. The average surface soil nutrients were calculated from 30 and 37 sampling points in the CA and the CB respectively. High values of five soil nutrients were found in the CB, and Figure 2 exhibits their spatial distribution. Values of AN (0.369 mg/100g), AP (0.519 mg/kg), SOM (0.03%), TN (0.005%) and TP (0.002%) in CB were higher than that in the CA. All the soil nutrients in the surface soil had lower values than that in the sediment in the CA on 10 July and 20 July, as has been noted by many authors (Liu *et al.*, 1995; Wang and Liu, 1999). This may be attributed to the sediment coming from cultivated soil which contained many compounded particles with high nutrients. The ratio of soil nutrient between sediment and surface soil varied significantly. The largest difference existed in the ratio for AP among five soil nutrients on the above-mentioned two events, with the second greatest difference in TN. AP of sediment was 5.14 and 10.84 times higher than that of surface soil.

In general, the high nutrient contents are found in the sediment of the first soil erosion occurrence during a year, but our results are contrary to this. At the same time, the ratio of soil nutrient between sediment and surface soil is larger than the values from 1.2 to 2.5 indicated by Chen and Zhang (1991) and Liu *et al.* (1995). There are two possible reasons for these

Table 1 Comparisons of runoff amounts and sediment yield between catchment A and catchment B

Catchment	Area (ha)	1999-7-10				1999-7-20			
		Rainfall (mm)	Rain intensity (mm min^{-1})	Runoff (m^3)	Sediment yield (kg ha^{-1})	Rainfall (mm)	Rain intensity (mm min^{-1})	Runoff (m^3)	Sediment yield (kg ha^{-1})
Catchment A	14.25	10.64	0.38	25.33	49	16.15	0.37	10.98	22.27
Catchment B	7.76	10.64	0.38	-	-	16.15	0.37	-	-

Table 2 Comparisons of nutrients between surface soil and sediment in catchment A and catchment B

	Soil organic matter (%)			Total N (%)			Total P (%)			Available N (mg/100g)			Available P (mg/kg)		
	*Soil	S 1	S 2	Soil	S 1	S 2	Soil	S 1	S 2	Soil	S 1	S 2	Soil	S 1	S 2
Catchment A	0.463	0.714	1.12	0.031	0.090	0.107	0.058	0.066	0.067	2.726	5.69	8.37	1.631	8.375	17.675
Sediment/Soil		1.54	2.42		2.84	3.38		1.14	1.15		2.09	3.07		5.14	10.84
Catchment B	0.494	-	-	0.036	-	-	0.06	-	-	3.095	-	-	2.15	-	-

* Soil represents the nutrient contents of 0-20 cm surface soil. S 1 and S 2 indicate the nutrient contents of sediment 1 and sediment 2 on 10 and 20 July respectively.

differences. First, their researches were based on artificial plot with small area and simple plant predominating crops, but our study was natural catchment with different types of land use. Second, the local farmers fertilized the cropland after the first rainfall. In addition, this also indicated that high nutrient in the soil lost more than low soil when soil erosion happened.

Based on calculated soil nutrient contents of runoff and sediment, the CB would lose 653.5 g ha^{-1} less in soil organic matter, 69.8 g ha^{-1} less in total N and 47.4 g ha^{-1} less in total P under similar rain conditions in comparison with the CA. This implies that the CB is a better land use structure for soil and water conservation.

4 Discussion

Soil erosion process happens when rain intensity exceeds soil infiltration in the Loess Plateau of China. Because soil physical properties and initial soil moisture had a close relationship with infiltration rate (Philip, 1957), they would have a huge impact on infiltration capacity (Jiang *et al*., 1997; Boix-Fayos *et al*., 1998). However, land use affects soil physical properties and evapotranspiration (Zhu, 1993; Le Roux *et al*., 1995) and further soil moisture (Fu *et al*., 2000). Moreover, the results from our study also demonstrated that there was significant difference in spatial pattern of soil moisture and soil nutrients because of different types of land use (Wang *et al*., 2002; Qiu, 2003).

According to the spatial pattern of soil moisture combined with land use type and position, different hydrological response units could be recognised (Flugel, 1995). For a specific hydrological response unit, there may exist a threshold value determined by the infiltration capacity for runoff and erosion to occur (Liu and Kang, 1999). Overland flow would occur on a unit only when the rain intensity reaches or exceeds the critical infiltration threshold for a given storm event. However, at the slope scale, the potential surface runoff-producing areas depend on the spatial arrangement of the hydrological response units. If differences exist in the neighboring units, runoff-producing areas would be spatially separated because of the differences in the time of surface runoff occurrence. Therefore, overland flow will be re-absorbed by the higher infiltration capacity (close drier) areas acting as sinks, and continuous flow along the slope would not come into being. At a catchment scale, widespread runoff occurrence must exceed most of the threshold values of the hydrological response units at smaller scales. This would require a long-time and larger storm. Therefore, arranging a mosaic pattern of dissimilar hydrological response areas may be an effective strategy in runoff and erosion control (Fitzjohn *et al*., 1998). This pattern could be created through land use arrangement.

For a storm event, if its intensity is below the critical thresholds of hydrological units and land uses, runoff and erosion processes would not occur in the whole catchment (Figure 4C). If the intensity exceeds most of the infiltration threshold values of hydrological response units in a catchment, the larger areas would produce runoff regardless of the spatial distribution of land use (Figure 4A). The differences in initial soil moisture and infiltration rate may not be important under this condition. However, during many rain events similar to that on July 10 and 20, the initial soil moisture (Zhang and Liang, 1995; Western *et al*., 1998) and infiltration capacity (Liu and Kang, 1999) had an important impact on the runoff-generating and erosion processes (Figure 4B).

Similar land uses along a slope displayed similar soil physical properties and an increase in soil moisture from the top to the footslope would lead to a similar infiltration rate of response units. This may easily create many runoff-producing areas at the same time and result in continuous hydrological pathways in a whole slope. For example, larger areas contributed to the runoff in the CA on the events of 10 and 20 July because the rain intensity exceeded the thresholds of the majority of the hydrological response units. However, the hydrological response units with dissimilar initial soil moisture and infiltration rate in a slope would induce differences in the time and amounts of runoff, and then give rise to an unconnected overland flow way. This would reduce the possibility of runoff and erosion. Our results showed that there was almost no overland flow and runoff in the CB for the two storms. Therefore, minimizing runoff occurrence and erosion could be achieved by creating a mosaic of land use, where suitable land use is selected, based on the spatial pattern of soil moisture. Cultivated land occupied most of the CA area. Its soil moisture displayed a pattern of increasing values from the top to the footslope and therefore easily produced spatial continuous flow pathway. At the same time, the CA may tend to suffer from more wind erosion because of the concurrent harvesting of crops. Therefore, the buffer zones (different vegetation strips) should be established to re-absorb runoff and trap sediments from the upper slope in the CA. The establishment of buffer zones would be helpful to not only control soil and water loss but also promote habitat diversity (Morgan, 1992; Fu *et al.*, 2000). In addition, land use management strategies aiming at encouraging infiltration rate such as building terraces and cropland abandonment for fallow reduce the frequency of runoff occurrence on a slope and catchment scale in this area.

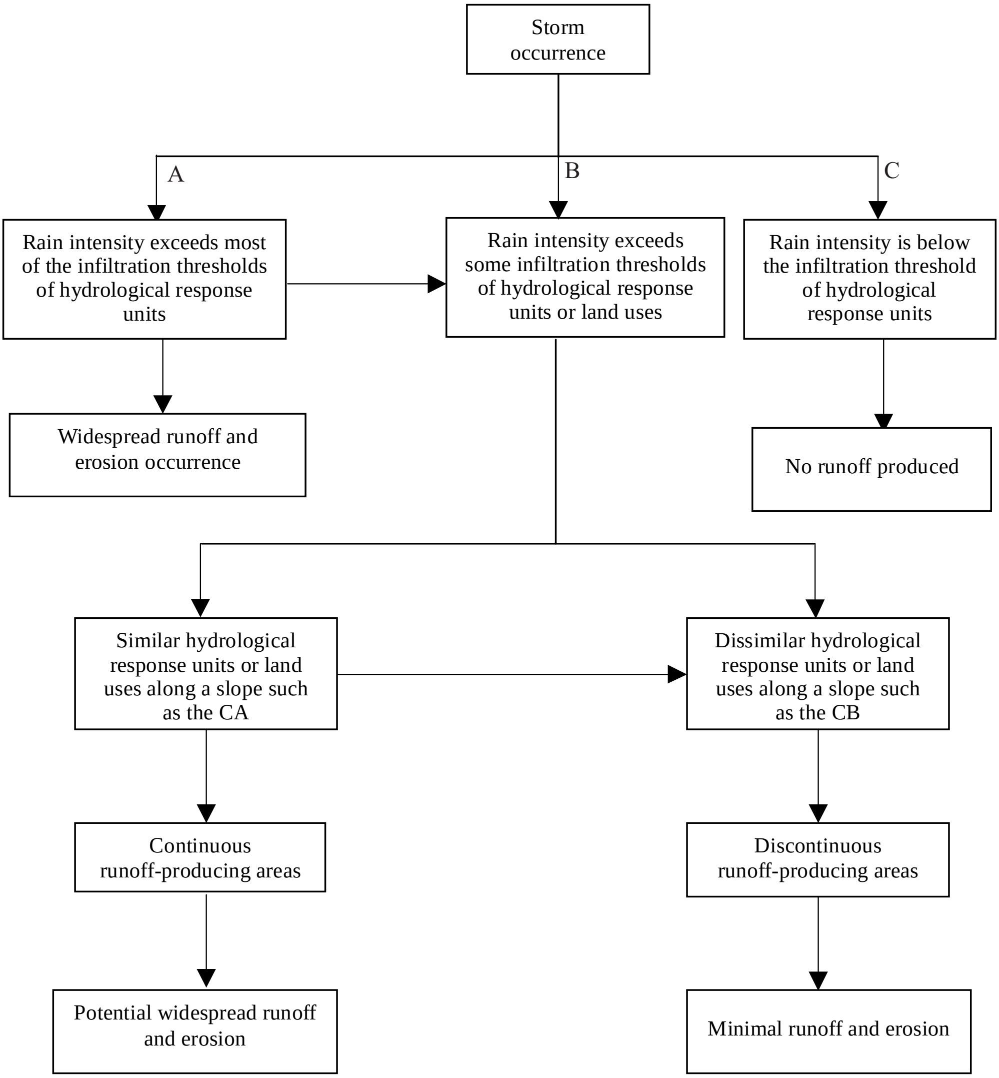

Figure 4 Runoff-producing mechanism and conceptual model for soil erosion control in the Loess Plateau

5 Conclusions

(1) Irrational land use has caused serious soil and water loss in the hilly areas of the Loess Plateau, and the effects of land use on runoff and soil nutrient losses were studied in this paper. Land use structures of the CB consisting of cropland (37%), fallow land (5%), shrubland (10%), intercropping land (43%) and woodland (5%) were different from the CA including cropland (76%), grassland (22%) and shrubland (2%).

(2) The CA produced an average sediment yield of 49 kg ha^{-1} and 22.27 kg ha^{-1} after rainfall of 10.64 mm lasting 28 minutes and 16.15 mm lasting 44 minutes respectively, whereas runoff did not occur in the CB. Compared with the CA, the CB could decrease 71.27 kg ha^{-1} of soil loss under similar rain conditions.

(3) Values of SOM (0.03%), TN (0.005%), TP (0.002%), AN (0.369 mg/100g) and AP (0.519 mg/kg) in the CB were higher than that in the CA. The ratio of soil nutrient between sediment and surface soil varied from 1.14 times to 10.84 times. The CB would decrease losses in SOM of 653.5 g ha^{-1}, in TN of 69.8 g ha^{-1} and in TP of 47.4 g ha^{-1} under similar rain conditions in contrast to the CA.

(4) In order to reduce runoff and erosion occurrence, a catchment with similar land use such as the CA should introduce buffer zones to create land use mosaic. Moreover, it is very helpful for soil and water conservation to increase infiltration rate and critical infiltration threshold value of land use during land use management such as building terraces and abandonment of cropland for fallow.

References

Bárdossy A, Lehmann W, 1998. Spatial distribution of soil moisture in a small catchment (Part 1): geostatistical analysis. *Journal of Hydrology*, 206: 1-15.

Bissonnais Y L, Benkhadra H, Chaplot V *et al*., 1998. Crusting, runoff and sheet erosion on silty loamy soils at various scales and upscaling from m^2 to small catchments. *Soil & Tillage Research*, 46: 69-80.

Boix-Fayos C, Calvo-Cases A, Imeson A *et al*., 1998. Spatial and short-term temporal variations in runoff, soil aggregation and other soil properties along a Mediterranean climatological gradient. *Catena*, 33: 123-138.

Chen H, Zhang S, 1991. Nitrogen and phosphorus movement from loess tillage under modelling the rainfall-runoff erosion processes. *Scientia Geographica Sinica*, 11(2): 142-148. (in Chinese)

Chen Y Z, Luck S H, 1989. Sediment sources and recent changes in the sediment load of Yellow River, China. In: S Rindwanich (ed.), Land Conservation for Future Generations, the Ministry of Agriculture, Bangkok, 313-323.

Conway A, 1978. Soil Physical-chemical Analysis. Institute of Soil Science, CAS, Nanjing. Shanghai, China: Technology Press, 76-78. (in Chinese)

Deidda R, 2000. Rainfall downscaling in a space-time multifractal framework. *Water Resour. Res*., 36 (7): 1779-1794.

Editorial Committee, 1996. Soil Physical and Chemical Analysis & Description of Soil Profiles. Beijing: Standards Press of China, 266pp. (in Chinese)

Emteryd O, 1989. Chemical and physical analysis of inorganic nutrients in plant, soil, water and air. Stencil No. 10. Swedish University of Agricultural Sciences, Uppsala, Sweden.

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.

Flugel W A, 1995. Delineating hydrological response units by geographical information system analyses for regional hydrological modelling using PRMS/MMS in the drainage basin of the river Brol, Germany. *Hydrological Processes*, 9: 423-436.

Francis C F, Thomes J B, Romero D A *et al*., 1986. Topographic control of soil moisture, vegetation cover and land degradation in a moisture stressed Mediterranean environment. *Catena*, 13: 211-225.

Fu B J, Gulinck H, 1994. Land evaluation in area of severe erosion: the Loess Plateau of China. *Land Degradation & Rehabilitation*, 5(1): 33-40.

Fu Bojie, Chen Liding, Ma Keming *et al.*, 2000. The relationships between land use and soil conditions in the hilly area of the Loess Plateau in northern Shaanxi, China. *Catena*, 39: 69-78.

Jiang D S, 1997. Soil Erosion and Control Models in the Loess Plateau. Beijing: China Hydroelectricity Press. (in Chinese)

Le Roux X, Bariac T, Mariotti A, 1995. Spatial partitioning of the soil water resource between grass and shrub components in a west African humid savanna. *Oecologia*, 104: 147-155.

Li G, Luk S H, Cai Q G, 1995. Topographic zonation of infiltration in the hilly loess region, North China. *Hydrological Processes*, 9: 227-235.

Liu B Z, Li G L, Wu F Q *et al.*, 1995. The regular patterns of the loss of soil nutrients on southern Loess Plateau. *Journal of Soil and Water Conservation*, 9(2): 77-86. (in Chinese)

Liu X D, Kang S Z, 1999. Some developments and review of rainfall-infiltration-runoff yield research. *Bulletin of Soil and Water Conservation*, 19(2): 57-62. (in Chinese)

Ludwig J A, Tongway D J, Marsden S G, 1999. Stripes, strands or stipples: modelling the influence of three landscape banding patterns on resource capture and productivity in semi-arid woodlands, Australia. *Catena*, 37: 257-273.

Morgan R P C, 1992. Soil conservation options in the U.K. *Soil Use Manage.*, 8: 176-180.

Ng E, Miller P C, 1980. Soil moisture relations in the southern California chaparral. *Ecology*, 61(1): 98-107.

Nielsen D R, Biggar J W, Erh K T, 1973. Spatial variability of field measured soil water properties. *Hilgardia*, 42: 214-259.

Parkinson J A, Allen S E, 1975. A wet oxidation procedure suitable for determination of nitrogen and mineral nutrients in biological material. *Communications in Soil Science and Plant Analysis*, 6: 1-11.

Philip J R, 1957. The theory of infiltration: 5. the influence of the initial soil moisture content. *Soil Science*, 83: 329-339.

Phillips J D, 1992. Deterministic chaos in surface runoff. In: A J Parsons, A D Abrahams (eds.), Overland Flow: Hydraulics and Erosion Mechanics. London: UCL Press, 177-197.

Qiu Yang, 2001. Spatiotemporal variation in land quality properties and their environmental effects in a gully catchment of the Loess Plateau, China. In: Ph.D. Dissertation of Research Center for Eco-Environmental Sciences, CAS. (in Chinese)

Qiu Yang, Fu Bojie, Wang Jun *et al.*, 2002. Variability of soil physical properties in the Loess Plateau. *Scientia Geographica Sinica*, 57(5): 587-594. (in Chinese)

Rai S C, Sharma E, 1998. Comparative assessment of runoff characteristics under different land use patterns within a Himalayan watershed. *Hydrological Processes*, 12: 2235-2248.

Reynolds S G, 1970. The gravimetric method of soil moisture determination: Part 3. an examination of factors influencing soil moisture variability. *Journal of Hydrology*, 11: 288-300.

Wang B Q, Liu G B, 1999. Effects of relief on soil nutrient losses in sloping fields in hilly region of Loess Plateau. *Journal of Soil Erosion and Soil and Water Conservation*, 5(2): 18-22. (in Chinese)

Wang Jun, Fu Bojie, Qiu Yang *et al.*, 2001. Geostatistical analysis of soil moisture variability on Da Nangou catchment of the Loess Plateau, China. *Environmental Geology*, 41: 113-120.

Wang Jun, Fu Bojie, Qiu Yang *et al.*, 2002. Study on spatiotemporal distribution of soil moisture in a small catchment of Loess Plateau using interpolation. *Progress in Natural Science*, 12(4): 430-433. (in Chinese)

Wang Jun, Fu Bojie, Qiu Yang *et al.*, 2003. Analysis on soil nutrient characteristics for sustainable land use in Da Nangou catchment of the Loess Plateau, China. *Catena*, 54(1-2): 17-29.

Western A W, Günter B, Rodger B G, 1998. Geostatistical characterisation of soil moisture patterns in the Tarrawarra catchment. *Journal of Hydrology*, 205: 20-37.

Young W J, Marston F M, Davis J R, 1996. Nutrient exports and land use in Australian catchments. *Journal of Environmental Management*, 47: 165-183.

Zhang G H, Liang Y M, 1995. Study on runoff beginning time of artificial grassland in loess hilly region. *Journal of Soil and Water Conservation*, 9(3): 78-83. (in Chinese)

Zhu Z C, 1993. The main characteristics of the vegetation and its impact on the soil essence in the Loess Plateau of northern Shaanxi province. *Acta Phytoecologica et Geobotanica Sinica*, 17(3): 280-286. (in Chinese)