Land Use Effects on Soil Erosion and Phosphorus Loss in the Hilly Area of the Loess Plateau, China

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Abstract: The Loess Plateau is one of the most seriously eroded areas in the world. This study determined the effects on runoff, soil loss, and phosphorus loss of six land use systems in hillslope of the Loess Plateau: farmland, wasteland and four forest treatments (Seabuckthorn + poplar, immature seabuckthorn, mature seabuckthorn, and immature Chinese pine). Differences were significant (P<0.05) for runoff and erosion among treatments. Runoff, soil loss, and P loss occurred mainly during critical period (July). Three of the four forest treatments (Seabuckthorn + poplar, immature seabuckthorn, and mature seabuckthorn) were reasonable land uses in limiting runoff, soil loss, and have the positive impact on the environment. The results indicated that farmlands over 15° produce more runoff, soil loss, and total P loss, and they should be reforested.

Keywords: land use, soil erosion, P loss, hilly area, loess plateau

1 Introduction

Soil loss in most areas of the Loess Plateau usually measures 5,000 Mg • km^{-2} • yr^{-1}—10,000 Mg • km^{-2} • yr^{-1}, with a maximum of 20,000 Mg • km^{-2} • yr^{-1} (Chen and Luk, 1989; Jiang, 1997; Wu and Yang, 1998; Chen *et al*., 2001). About 1.6 billion tons of sediments per year were delivered into the Yellow River. This is likely to be a major source of non-point pollution for water contamination of the Yellow River downstream due to chemical transport (Nelson and Ehni, 1976; Myers *et al*., 1985). As the most common land use in the Loess plateau, farming on sloping land contributes most of the sediment delivered into the Yellow River (Tang and Chen, 1991; Fu *et al*., 2000).

As one of the most seriously eroded areas in the world, the Loess Plateau has received a lot of attention from the Chinese government and internationally (BREST-CAS, 1992;Yang and Yu, 1992; Lu *et al*., 1997; Jiang *et al*., 1997; Wu and Yang, 1998). In 2000, the Chinese government began to carry out the Western Development Programme. Control of soil erosion and the development of an ecologically sustainable environment in the Loess plateau are two important parts of it. At present, the population density of the Loess Plateau is about 144 persons per kilometer (Wu and Yang, 1998), and the overwhelming majority is subsistence farmers. Control of soil erosion centers on land management practices which may affect the daily activities of millions of people. So it is important to study the effects of different land use systems in the Loess plateau on soil erosion and nutrient loss.

Phosphorus is an essential element for plant and its input has long been recognized as necessary to maintain profitable crop and meet global food requirements (Hedley and Sharpley, 1998; Sharpley and Tunney 2000). Also, P inputs to fresh waters from agricultural lands can accelerate eutrophication (Schindler, 1977; NRC 1992,1993; Newman 1995; Nixon *et al*., 1996; U.S. EPA 1996; Carpenter *et al*., 1998). Many existing studies have quantified P losses via runoff and soil loss from specific sources such as fields varying in tillage and fertility management, buffer strips, riparian zones, terracing, contour tillage, cover crops, constructed wetlands, impoundments (settling basins), tile drainage, barnyards, and drainage ways (Jone *et al*., 1987; Osborne and Kovacic, 1993; Sharpley *et al*. 1994; Sharpley and Simth 1994; Correll 1997; Cai and Wu, 1998; Chambers *et al*., 2000, Uusi-Kamppa *et al*., 2000;). However, very few studies have compared P losses from various sources under the same conditions (i.e., within a watershed) and quantified their inputs (e.g. Mass, 1988; Meng *et al*., 2001). Without the capability to quantify the importance of P sources, remedial practices cannot be effectively targeted (Sharpley and Tunney 2000). Therefore information regarding runoff and associated soil and nutrient losses from different land uses can provide valuable insight into the development of sustainable agricultural systems that optimize production and maintain high environmental quality (Thomas *et al.*, 1992). The present study was designed to address the general need for basic information on the effects of land uses on soil and nutrient (P) loss and to address the specific need for information about the reasonable utilization of more steeply sloping land in the Loess Plateau. The objectives of this study were to study the effect of land use on: (1) runoff and erosion, (2) P loss; and based on (1) and (2), to suggest sustainable land uses in the hillslope of the Loess Plateau.

2 Materials and methods

2.1 Site description

Seventeen field plots (5m by 20m) were established in 1992 at An'sai Soil And Water Conservation Station (36° 41′N, 110° 58′E), An'sai county, Shaanxi province (Fig. 1). All the plots were on calcic cambisols (FAO-UNESCO, 1974), which is weakly resistant to erosion. In 1997, seabuckthorn in plots 3 and 4 was cut down and the regrowth was used as immature seabuckthorn. To avoid the effects of position, all plots were established in one line (Fig. 2). They were oriented parallel to the slope and adjacent to each other, with borders to isolate plot runoff and sediment. A discharge ditch was created at the top of each plot to control runoff and sediments from the upper slope. At the base of each plot, two volumetrically calibrated tanks were arranged in series for runoff and sediment collection.

The station is in northern part of the Loess Plateau which has a subarid climate. Mean annual precipitation is about 473.9 mm (1929—1980), with about 60% falling between June and September (Fig. 3). The maximum rainfall recorded is 851.0 mm in 1964, and the minimum is 296.6 mm in 1974. The average annual potential evapotranspiration is 1,556 mm (Shaanxi Province Meteorology Bureau, 1992). The average annual temperature is 8.8°C, and there are 159 frost-free days.

2.2 Treatment and management

Field plots were assumed to represent land uses, and six land use treatments were used in this study, each replicated twice (Fig. 2). Land use were: Plots 1 and 2: seabuckthorn (*Hippophae xhammoides*) + poplar (*Populus simonii*) (SP); Plots 3 and 4: immature seabuckthorn (*Hippophae xhammoides*) (IS); Plots 5 and 6: farmland (FR); Plots 7 and 8: wasteland (WS); Plot 9 and 10: immature Chinese pine (*Pinus tabulaeformis*) (ICP); Plots 11 and 12: mature seabuckthorn (*Hippophae xhammoides*) (MS). These 12 plots were established at lower slope with a uniform slope of 24°. In order to test different slope treatments, at the top of the same slope, five plots without replication (plots 13—17) were established: farmlands at 10°, 15°, 20°, 25°, and 30°.

There was a apparent humus layer in the SP, MS, and IS treatments. Millet with contour tillage was planted continuously in farmlands. Fertilizer (at N, P rates of 120, and 60 kg/ha) was applied in farmland prior to planting and mixed into the soil by harrowing.

2.3 Methods

Runoff and sediments were collected in two volumetrically calibrated tanks arranged in series at the base of each plot. As soon as each erosive event ended, depth of runoff in each tank was measured and the runoff sampled to determine sediment content, then all tanks were emptied.

Aliquot samples (1L) of runoff were centrifuged at 2,500 rpm for 30 min to separate sediment from the liquid. The supernatant liquid obtained after centrifuging was sent to analyze *P* contents in 24 hr. Settled sediment was air-dried and weighed to calculate concentrations in grams per liter. Samples (250 ml) of rainfall, taken from the recording rain gauge, were analyzed for *P* contents.

Water samples (including runoff and rainfall sample) were analyzed as follows: after digestion with $K_2S_2O_8$, total *P* was determined calorimetrically. Soil and sediment samples were air-dried, and passed through 1.0 and 0.15 mm sieves. total *P* calorimetrically after wet digestion with $H_2SO_4 + HClO_4$.

Flow of runoff was expressed as:

$$\text{Flow (L)} = \text{Runoff depth (cm)} \times \text{the square measure of tank (cm}^2) \times 10^{-3}$$

P loss was expressed as the following equation:

P loss in runoff=[Nutrient conc. (mg • L^{-1})×Flow (L)] × N

P loss in sediments=[Nutrient conc. (g • kg^{-1}) × Weight (kg)] × N

Where n is the total number of erosive storms in each year.

3 Results and discussion

3.1 Effects of land use on runoff and sediment

There were total five erosive storms in 2000, and they were all in July and August (Table 1). No erosion-generating storms occurred after August 2000. Usually there are 2—3 erosive storms in An'sai station annually and more than average in 2000.

Runoff from different land uses was summarized in Table 1. Significant differences ($P<0.05$) in total runoff and soil loss were observed among treatments (Table 1, Fig. 4 and 5). It meant that, through adjusting land use practices, we could control soil erosion.

The expected low runoff and corresponding erosion from SP, ST, and SA were related to the dense canopy cover and litter, which enhanced rainfall interception and surface detention. Furthermore, favorable soil properties, reflected in the humus layer in plots, resulted in infiltration exceeding rainfall rates, thereby negating runoff (Komass *et al.*, 1992; Thomas *et al.*, 1992; Rai and Sharma, 1997; Sttot, 1999). No soil loss was observed in SP, ST, and SA (Fig. 5). Expect for shield of the dense canopy cover and litter, the small numbers of observations may also response for it, although erosive storms in 2000 are more than average.

CPT and WS produced more runoff and sediment than SP, ST, and SA. It even produced more runoff than FR (24°) in August. Sediment from CPT and WS was much less than that from FR (24°) (Fig. 5). This was due to the surface conditions of CPT and WS that prevented downslope movement of soil. If used as component of landscape diversity, CPT at 24° would produce more runoff and soil loss and so was not reasonable.

Total runoff and soil loss of FR was much more than that of the other land uses (Table 1, Fig. 4 and 5). The result was primarily attributed to the component of loess (Fu, 1989; Fu and Gulinck, 1994) and thin crop cover, which resulted in rainfall rates exceeding infiltration (Norton *et al.*, 1999). With high rainfall frequency and long duration, increasing soil water content reduced the infiltration rate and runoff increased steadily.

According to the above discussion, FR produced much more runoff and soil loss, and it is the most common land use in Loess Plateau. So we tested the slope treatment of FR. Runoff and soil loss from FR (10°—30°) concentrated in the first erosive storm in July, and it was different with that of FR (24°) (Table 1). This meant that position might influence runoff and soil loss from FR.

Total runoff changed little among FR of 15°, 20°, and 25° (Table 1), while there were little differences of total soil loss among FR of 20°, 25°, and 30° (Fig. 6). The amount of total runoff and sediment from FR of 15°, 20°, and 25° was much more that of FR of 10°. So for the purpose of reducing runoff and soil loss, farmlands of over 15° should be reforested. 30° might be the threshold degree for runoff, because when slope reached 30°, total runoff (645L) began to decreased, and even less than that (858L) of 10°(Table 1).

Lots of researchers had defined critical periods for runoff and erosion from agricultural land in terms of periods when soil was least protected and hence more vulnerable to erosion by excess runoff than during times when crop canopy or residue provided adequate cover (Yoo and Touchton, 1988). In our study, the critical periods should be July. Runoff and sediment were more in critical periods than in non-critical periods when crop stand and canopy cover reduced runoff amounts and so sediments (Fig. 4 and Fig. 5). Differences between the two periods were significant ($P<0.05$) for runoff but non-significant for soil loss. Small numbers of observation and no soil loss data in SA, ST, and SP might be the reasons. But for FR (10°—30°) at upslope slope, differences between these periods were significant ($P<0.05$) for both runoff and soil loss. This indicated that, in order to effectively control soil erosion, more attention should be paid in July and for FR.

3.2 Effect of land use on *P* loss

In terms of the foregoing definition of critical period, total *P* loss in runoff was listed in Table 2. Except for SP, the relative proportion of total P loads was typically higher in July (Table 2). This might be due to the significant differences of runoff for critical and non-critical period (Fig. 4).

Higher non-critical period P loading in runoff of SP was related to the little changes of runoff for the two periods and decomposition of surface residue from previous season (Thomas *et al*., 1992). And there were little differences of total *P* loss in runoff among SP, ST, and SA (Table 2). So the proportion of *P* losses among ST, SP, and SA in critical and non-critical period meant different modes of *P* movement existed among them. The plant structure and humus layer of SP, ST, and SA might response for this.

Total *P* loss in runoff was significantly higher of FR than of SP, ST, and SA. This difference was attributed primarily to fertilization on FR plot (Meng *et al.*, 2001). There were no differences to total *P* losses in runoff among FR, WS, and CPT (Table 2), although runoff among them had much changes (Table 1). This indicated the high *P* solubility and mobility in July of WS and CPT.

Table 3 summarized the Loading of total *P* loss in sediments. No *P* loss in sediments of SP, ST, and SA. *P* loss was higher in sediment for FR than for WS and CPT, and it was also higher during critical than non-critical period. This was attributed mainly to fertilization and higher amount of soil loss from FR than from WS and CPT. Compared to Table 2, total P loss in SP, ST, and SA was primarily through runoff, and sediments were the main sources of total P loss in FR, WS, and CPT. The role of sediment load in total *P* loss corresponded to the findings by others (Angle *et al*., 1984; Sharpley *et al*., 1991; Huang *et al*., 1998). In the case of P mobilization, adsorption to particles is an especially important mode of transportation (Gilliam *et al*., 1985).

The same trends of *P* loss in runoff and sediment existed in farmlands (10°—30°). The relative proportion of total *P* loads was typically higher in critical than in non-critical period, and sediments were the main sources of total *P* loss, not runoff. Despite receiving the same annual *P* fertilizer rate, *P* loss in runoff decreased with slope increasing, while *P* loss in sediment increased with slope increasing, especially when slope surpass 15° (Table 3). This was related to changes of runoff and sediment yields from FR (10°—30°) (Table 1; Fig. 6). The more loss of *P* from FR over 15° not only made the on-site productivity down, but also accelerated the eutrophication of the downstream location.

Adding Table 2 and Table 3 together, we would get the total *P* loss in soil erosion. The amount of total *P* loss from the six land uses was: FR>CPT>WS>ST>SP>SA, and from FR (10°—30°) was: 25°>20°>30°>15°>10°. CPT at 24° not only produced more runoff and soil loss, but also caused more *P* loss. More runoff, soil loss, and *P* loss from WS than from ST, SA, and SP showed the importance of plant cover for controlling soil erosion.

4 Conclusion

More total runoff and sediment from FR than from SP, ST, and SA reflected the protective effects of continuous vegetation cover. FR over 15° would be reforested for it produced more runoff and soil loss. Runoff and sediment from the six land uses were mainly produced in critical period when the soil was largely exposed.

Peak *P* loss occurred during the critical period and from FR. And a considerably larger proportion of total *P* loss occurred in the sediment fraction. 15° is also a threshold limit value for *P* loss from FR. CPT not only produced more runoff and soil loss, but also caused more *P* loss. As component of landscape diversity, it should be located at slope of less than 24°.

SP, ST, and SA produced less runoff and soil loss than FR, WS, and CPT. They will also decrease nutrients loading in surface waters and so have a positive impact on the environment. FR (<15°) offers the potential for achieving environment quality while simultaneously maintaining high production levels. By extrapolating the results to the hilly area of Loess Plateau, the sustainable land uses SP, ST, and SA.

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