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Soil management effects on runoff and soil loss from field rainfall simulation

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ABSTRACT

Soil erosion from agricultural lands is a serious problem on the Chinese Loess Plateau. In total, 28 field rainfall simulations were carried on loamy soils under different management practices, namely conventional tillage (CT), no till with mulch (NTM), reduced tillage (RT), subsoiling with mulch (SSM), subsoiling without mulch (SS), and two crops per year (TC), to investigate (i) the effects of different soil management practices on runoff sediment and (ii) the temporal change of runoff discharge rate and sediment concentration under different initial soil moisture conditions (i.e. initially dry soil surface, and wet surface) and rainfall intensity (85 and 170 mm h^{-1}) in the Chinese Loess Plateau. NTM was the best alternative in terms of soil erosion control. SSM reduced soil loss by more than 85% in 2002 compared to CT, and its effects on runoff reduction became more pronounced after 4 years consecutive implementation. SS also reduced considerably the runoff and soil loss, but not as pronounced as SSM. TC resulted in a significant runoff reduction (more than 92%) compared to CT in the initial ‘dry’ soil, but this effect was strongly reduced in the initial ‘wet’ soil. Temporal change of runoff discharge rate and sediment concentration showed a large variation between the different treatments. In conclusion, NTM is the most favorable tillage practices in terms of soil and water conservation in the Chinese Loess Plateau. SSM can be regarded as a promising measure to improve soil and water conservation considering its beneficial effect on winter wheat yield.

1. Introduction

Erosion is one of the main problems that the agricultural sector on the Chinese Loess Plateau is confronted with. The total eroded area of the Loess Plateau is 454,000 km^2, of which 337,000 km^2 is affected by water erosion (YRCC, 2002). The average erosion rate of cultivated land on the Loess Plateau is estimated at 60 ton ha^{-1} y^{-1} (Luk, 1996).

The conventional tillage methods in the Chinese Loess Plateau use moldboard plows and harrows pulled by animals or tractors and are based on the principle that all crop residues are removed from the fields before a new crop is sown or planted in a fine, loose and smooth soil (Cai et al., 2006.). The rationale of the farmer is that the advantages are clear: weeds are well controlled and the sowing and planting operation can be done effectively. However, the conventional farming practices are very far from being sustainable and environmentally compatible from a soil and water conservation perspective because of the uncovered soil surface during July, August and September, which are characterized by the highest rainfall intensities (more than half of the total annual rainfall occurs during this period), and because of the conventional up and down the slope ploughing (Jin et al., 2003; Zhang et al., 2007). In recent years, irrational agricultural practices have been continuing to deteriorate the environment and to decline land productivity in the Chinese Loess Plateau (Lal, 2002; Schiettecatte et al., 2005; Wang et al., 2006). Therefore, developing and adopting more effective cropping systems and tillage practices are the keys to bring soil erosion under control and to achieve sustainable crop production in the Chinese Loess Plateau (Li et al., 2002).

As a consequence, conventionally tilled winter wheat in the Loess Plateau is now gradually shifting towards conservation tillage because of economic and soil and water quality benefits associated with conservational tillage production (Wei et al., 2000). Several researchers have already indicated that conservation tillage practices reduce soil and nutrient losses considerably (e.g. Mostaghimi et al., 1988; Kisic et al., 2002; Puustinen et al., 2005).

Maintaining a crop residue cover and standing stubble after harvest in conservational tillage are two important factors controlling the intensity and the frequency of overland flow and surface wash erosion. Both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Kosmas et al., 1997). Rainfall

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Fig. 1. The exterior landscape of experiment site.

simulation experiments conducted by Mostaghimi et al. (1988) on a silt loam, showed a strong decrease in runoff and soil loss as the residue level of winter rye increased, regardless of the tillage system (no till and conventional till). Surface residues that cover only 20% of the soil surface can already substantially reduce soil loss compared with a bare surface (Johnson and Moldenhauer, 1979), while above 60% of coverage, the bare areas are generally too small and discontinuous to contribute to runoff of erosion at the field scale (Le Bissonnais et al., 2005). Cogo et al. (1984) found that a standing stubble reduced soil erosion by water more than surface roughness did, especially when residue cover was present. Retention of wheat stubble in situ without incorporation (standing stubble in furrows) can minimize erosion and runoff and consequently maximize water infiltration (Mostaghimi et al., 1998).

Our primary objective was to investigate plot-level runoff and soil losses via overland flow by analyzing the temporal change of runoff, sediment concentration, and sediment load in runoff and to determine the magnitude of runoff and sediment under different soil management practices. For the plots where runoff occurred, we focused particularly on the overland flow patterns (e.g., time to initiate runoff, runoff volume, sediment discharge rate, runoff peak flow) at different temporal scales of measurement. These results are needed to select and promote valid tillage alternatives for abating soil erosion and nutrient losses in the Chinese Loess Plateau by introducing improved land management strategies so as to improve yields whilst minimizing soil loss and reducing nutrient inputs.

2. Materials and experimental designs

2.1. Site description

An experimental site aimed specifically at monitoring the impact of converting conventional tillage to conservation tillage was established in Songzhuang Village, 25 km north of the city of Luoyang (Henan Province; 113.0° East longitude, 34.5° North latitude) (Fig. 1) in the eastern part of the Chinese Loess Plateau. In this region, the Quaternary loess has a thickness varying from 50 to100 m. It has a loose and porous structure with high hydraulic conductivity. The soil in the study area was a silt loam soil and classified as Ustochrept according to Soil Taxonomy (Soil Survey Staff, 2003).

The experimental site was previously conventionally tilled for over 30 years and the basic soil properties were analyzed before the establishment of the experimental plots (Table 1). There was no significant difference between the tested properties ($p<0.05$). Since the entire experimental site was relatively homogenous in terms of soil physical, chemical and topographic properties, the different treatments could be laid out as single plots which reduced the total size of the experimental site and hence variability. Statistical analysis of the effects of different soil management practices could therefore be conducted using the results from replicated samples in one single plot (Zhang et al., 2006).

Two series of plots were laid out: one series of five plots under natural rainfall (set up in 1999) and another series of four plots was designed specifically for rainfall simulation tests (set up in 2001) on a 'gullied hill'. Gullied hilly loess consists of rounded hills of considerable height with a high density of steep-sided gullies showing evidence of active erosion. Each plot under simulated rainfall was 15 m long and 1.8 m wide. The slope of the plots, which were located along the same contour line, was 9%.

During 1970–2006 the minimum temperature was −23.5 °C and the maximum was 43.7 °C. The average annual precipitation during the study period was 580 mm. The annual potential evaporation varied between 1262 and 1852 mm and the average air humidity was 65%. Rainfall was unevenly distributed throughout the year with high rainfall intensities and frequent rainstorms in summer (June–September) and dry winters (December–February).

Table 1
Soil characteristics in Songzhuang (Henan province) in 2001 ($n=6$)

Profile	Depth (m)	0–2 μm (g kg^{-1})	2–50 μm (g kg^{-1})	50–2000 μm (g kg^{-1})	Texture[a]	$CaCO_3$ (g kg^{-1})	Total N (g kg^{-1})	Bulk density[b] (Mg m^{-3})	pH (KCl)
A_o	0.00–0.02	143	748	109	Silt loam	113 (3)	1.124 (0.18)	1.350 (0.041)	7.7 (0.1)
A_p	0.02–0.30	141	743	116	Silt loam	129 (5)	0.955 (0.11)	1.350 (0.027)	7.8 (0.0)
B_1	0.30–0.60	138	745	117	Silt loam	142 (0)	0.732 (0.09)	1.383 (0.019)	7.7 (0.1)

Values between brackets indicate the standard deviation.
[a] USDA textural classification.
[b] $n=3$.