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Effects of tillage practices and slope on runoff and erosion of soil from the Loess Plateau, China, subjected to simulated rainfall

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ABSTRACT

Soil erosion, particularly during summer fallow period, in sloped farmland has been identified as a critical threat to sustainable agricultural development in the Loess Plateau of China. However, the effects of varying tillage practices during the summer fallow period have not been fully investigated. The objective of this study was to determine the effects of tillage practices on runoff and sediment loss under plot (4.0 m in length and 1.0 m in width) rainfall simulations. Runoff initiation time, runoff amount, sediment loss and cumulative infiltration amount were recorded. One rainfall intensity (90 mm h^{-1}, 40 min), three slopes (5°, 10°, and 15°) and four prevalent tillage practices (Artificial Digging, AD; Artificial Hoeing, AH; Contour Plow, CP; and Traditional Plow, TP) were studied. Two indices, runoff reduction benefits (RRB) and sediment reduction benefits (SRB), were selected to evaluate the effect of the practice on controlling runoff and sediment. Compared to TP treatment, the AD, AH and CP were more effective in reducing the magnitude of runoff amount and sediment loss as well as increasing the rain water infiltration amount. CP with a 15° slope was an exception in which the sediment loss increased. In general, the SRB was greater than the RRB for a given tillage practice under the same slope, suggesting that the benefits from sediment reduction were more effective than the benefits from runoff reduction. RRB and SRB were the largest for AD, followed by AH and CP, irrespective of slopes. The capacity of the three tillage practices to reduce runoff and sediment decreased as the slope increased. In particular, AD at a 5° slope had the best performance in reducing runoff and sediment loss; however, SRB and RRB were −57% and 1%, respectively, for a CP plot with a 15° slope. This finding suggested that CP had a higher sediment loss and a similar runoff amount compared to those of TP. These results of plot simulated rainfall will contribute to our knowledge about the effects of different tillage practices on soil erosion from sloped farmland.

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1. Introduction

In the Loess Plateau region of China, soil erosion on agricultural land, sloped farmland in particular, is regarded as a severe environmental problem and is a major sediment source for the Yellow River. Approximately 60% of the total watershed sediment and runoff amount is derived from sloped farmland (Tang, 2004). The severity of erosion in sloped farmland seems to be affected by tillage practices, which can have dramatic consequences such as the decline of soil fertility, deterioration of agro-ecological well-being as well as the hampering of agricultural economic growth (Lal, 1993; Pimentel et al., 1995; Swanepoel et al., 2015). Additionally, recent studies have highlighted that agricultural land erosion, which can be sensitively affected by human activities, plays an important role in the global soil carbon cycle (Amundson et al., 2015; Lal, 1993; Van et al., 2007). In the Loess Plateau of China, the availability of agricultural land has decreased as a result of increasing population as well as industrial and urbanization related construction. Therefore, farmers have to utilize sloped land in order to ensure sufficient food production (Tang, 2004). Reclamation activity can also significantly increase the risk of severe soil erosion (Engel et al., 2009; Shi and Shao, 2000). This is particular true for the summer fallow period in the Loess Plateau after summer tillage operation, which is an important contributor to soil erosion occurring in sloped farmland.

Tillage in the summer fallow period has been widely used for removing weeds, preparing the seed bed and minimizing soil evaporation, in dry regions in particular (Hammel et al., 1981; Vermang et al., 2015). Farmers conduct one-time tillage practices

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to create a favorable rough surface after harvest of winter wheat during May to June in the Loess Plateau region. After precipitation, farmers repeat tillage to breakup soil surface crusts formed after previous precipitation in order to maintain a rough soil surface. Commonly used summer tillage practices, like the use of plows or hoes, in the Loess Plateau region produce a rough soil surface. However, these summer tillage practices can make farmlands highly susceptible to severe soil erosion during the following rainy seasons. Furthermore, the majority of annual rainfall is concentrated in summer between July and September, and this accounts for 60–70% of the total annual rainfall amount in the Loess Plateau region (Shi and Shao, 2000). Since summer tillage operations occur in parallel with the period of bare sloped farmland, the annual soil loss may be increased by some extreme erosive rainfall events (Liu, 1999; Shipitalo and Edwards, 1998). Thus, the rainfall patterns and the fresh tilling of sloped farmland in summer contribute to the occurrence of extreme soil erosion.

More notably, tillage operations in the summer fallow period are important for increasing rainfall infiltration and soil water storage, especially for rainfed agricultural regions. Blanco and Lal (2008) proved that tillage of dry land in western US or Great Plains during the summer fallow period increases the gain of water for winter wheat and reduces runoff. Lee and Yang (1965) reported that summer plowing can improve the physical, chemical and biological soil conditions during the summer fallow period and this may increase winter wheat yield in the Loess Plateau. Similarly, several researches have described the effects of tillage practices on soil erosion (He et al., 2007; Jin et al., 2008; Puustinen et al., 2005; Raper et al., 2000; Rimal and Lal, 2009). Thierfelder and Wall (2009) found that tillage in dry land agriculture of Zambia and Zimbabwe decreased runoff and soil erosion, increased water infiltration, and therefore, improved rainfall water-use efficiency. Arnhold et al. (2014) reported the soil erosion rates on mountainous farmland for row crops and they found that when compared to conventional farming practices, organic practices can potentially decrease the risk of erosion for row crops. Basic et al. (2001) and Basic et al. (2004) investigated the effects of different slope tillage methods on runoff and soil loss. They analyzed the advantages and disadvantages of the tillage methods and found that appropriate tillage methods can play an important role in reducing the soil erosion to a tolerable level, although, the erosion processes in sloped farmland cannot be completely prevented. Temesgen et al. (2009) investigated the agronomic performance of conservation tillage practices in semi-arid regions and found that tillage practices can enable more rainfall water retention than a reduced tillage system under rainfed agriculture. Gómez et al. (2009) and Hernández et al. (2005) found that soil management methods minimize sediment and runoff losses by improving soil properties and biochemical fertility, thus increasing water infiltration and decreasing soil and runoff losses in rainfed olive orchards. Additionally, the support factor (P) in the Revised Universal Soil Loss Equation (RUSLE) reflects the effects of tillage mechanical practices, e.g. plow, contour furrow and chisel, on soil erosion (Renard et al., 1997). Liu et al. (2014) investigated the effects of microtopography and ridge geometry generated from ridge tillage on runoff and sediment yield. They found that ridge tillage reduced runoff and sediment yield and also had a negative effect on soil erosion control due to the occurrence of contouring failure in the ridge tillage system.

The above-mentioned studies have provided insights on the importance of tillage practices for soil erosion on sloped farmland; however, a general conclusion about the impact of tillage methods on soil and water loss still cannot be drawn. In the Loess Plateau, the effects of traditional tillage practices on soil and water loss in sloped farmland have been limitedly studied only. Additionally, many socio-economic and physiographical factors, such as steep slopes and small plot size, prevent small farmers from adopting mechanized manipulation, and therefore, they continue to use traditional manual or ox-drawn tillage methods. Thus, we hypothesize that tillage practices could be used as a protective management to reduce runoff and sediment loss during the summer fallow period. In order to test this hypothesis, the objective of this study was to investigate the potential effects of tillage practices on soil and runoff loss and rainfall infiltration

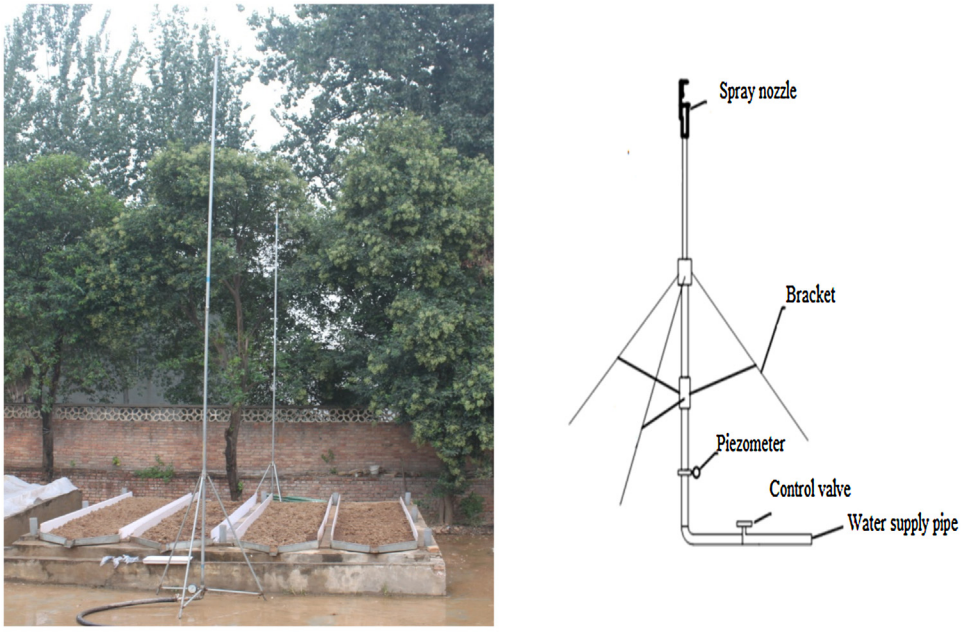

Fig. 1. Rainfall simulator and runoff plots (a) and the schematic of rainfall simulator (b).

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