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Exploring optimal measures to reduce soil erosion and nutrient losses in southern China

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ABSTRACT

Heavy rainfall becomes more variable and erratic in the subtropical areas, increasing unpredictable risks of soil erosion and nutrient losses on the sloping farmland. Soil management practice also plays an important role in soil erosion. However, the effects of management practices on soil erosion and nutrient losses in response to heavy rainfall remain uncertain. A field study was carried out under natural rainfalls, including five treatments: bare land as control (CK), downslope tillage (DT), hedgerows with downslope tillage (DT + HG), contour ridge tillage (CT) and straw mulch (SM). The effects of management measures on runoff depth, sediment yield and nutrient losses were evaluated during peanut growth. The results indicated that heavy rainfalls caused severer soil erosion and nutrient losses. Significantly reduced runoff and sediment loss were found in all the conservation measures ($p < 0.05$). Compared with CK, the runoff depths under DT, DT + HG, CT and SM were reduced by 10%, 37%, 49% and 81% respectively under heavy rainfalls. In addition, sediment loss under DT, DT+HG, CT and SM were 30.81, 7.42, 1.83 and 1.34 Mg ha−1, respectively. These values were 42%, 86%, 97% and 97% lower than that for CK, respectively. TN and TP losses were mainly controlled by sediment yield. The majority of nutrient losses occurred in the particulate fraction (93% of TN and 99% of TP). Generally, much of the TN and TP were transported by the particles < 0.05 mm. Over 51% of TN was transported by fractions of < 0.05 mm in CK and DT sediments under heavy rainfalls; in CT and SM, this percentage increased to 61% and 74%, respectively. The findings indicated that straw mulch is the most cost-effective management measure to control soil and nutrient losses in sloping farmland of southern China.

1. Introduction

Soil erosion caused by water is a significant cause of land degradation and productivity declines around the world (Fang et al., 2017; Prosdocimi et al., 2017; Rodrigo et al., 2016; Wei et al., 2017). Approximately 751 million ha of land worldwide is affected by moderate to severe water erosion processes (Lal, 2004). It may cause the detachment or redistribution of soil particles in the topsoil layer and lead to adverse impacts to the downstream (Quinton et al., 2010; Jarvie et al., 2013; López et al., 2016). Water and sediments transported by water erosion contain various nutrients removed from the soil, such as nitrogen and phosphorus, which are regarded as the principal nutrients causing eutrophication (Xu et al., 2013). The loss of excessive nutrients in agricultural areas reduces soil fertility; furthermore, the quality of water resources is being progressively degraded (Bertol et al., 2003; Baptista et al., 2015). Accelerated soil, water and nutrient losses are attributed to intense cultivation, inappropriate agricultural soil and water managements and erratic rainfalls.

Rainfall-runoff generation and the related soil erosion are extremely dynamic and complex processes, which are affected by many factors. Many studies have proved that rainfall characteristics (e.g. rainfall intensity, duration, pattern and rainfall energy) and soil management practices are the two primary factors influencing runoff generation and soil erosion (Truman et al., 2007; Girmay et al., 2009; Shipitalo et al., 2013; Wang et al., 2014). Among these factors, heavy rainfalls, in particular, play important roles in causing severe soil erosion and nutrient loss. For example, studies have showed that the annual nitrogen and phosphorus loss under extremely heavy rainfall exceeded 50% of the total loss amount (Gao et al., 2005). The temporal distribution of heavy rainfalls is particularly important for assessing runoff and erosion rate (Apaydin et al., 2006). Wei et al. (2007) also found that rainfall patterns with high intensity, short duration and high frequency were the dominant causes of runoff and sediment. There is no-doubt that the variability of natural rainfall will increase the complexity and

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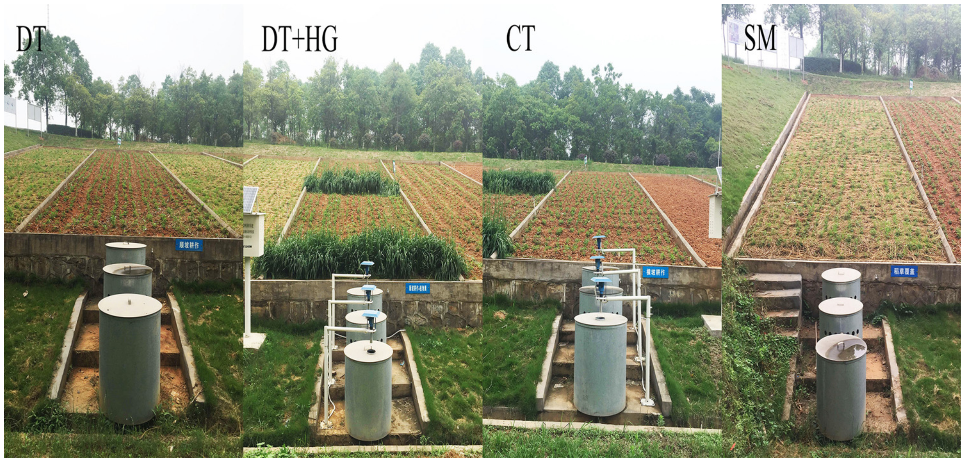

Fig. 1. Runoff plots of different management measures. *Note*: DT, downslope tillage; DT + HG, hedgerows with downslope tillage; CT, contour ridge tillage; SM, straw mulch.

uncertainty of runoff generation and erosion process. Extreme rainfall variability characterized by large precipitation, high rainfall intensity, few rainfall events, and poor temporal distribution, exert a direct impact on soil and water holding capacity, and associated nutrient levels (Brouder and Volenec, 2008). However, the deep rainfall-runoff-erosion relation is also greatly regulated by soil management practices (McHugh et al., 2007; Lanckriet et al., 2012; Dagnew et al., 2015).

Many studies have confirmed that various runoff and erosion responses occur under different soil management practices. Studies mostly focus on the effects of different management practices, such as conservation tillage (Hösl and Strauss, 2016), tied ridges (Ngetich et al., 2014), mulching (Okeyo et al., 2014; Grum et al., 2017), hedgerow systems (Kinama et al., 2007; Lin et al., 2009; Xia et al., 2013) on runoff generation and erosion processes. They concluded that application of appropriate management measures can be the key in reducing runoff and sediment loss. These management practices can intercept rainfall, reduce raindrop energy, improve infiltration of rainwater, enhance soil fertility and trap sediment compared to the conventional practices. For example, cropping studies in semi-arid Kenya conducted by Kinama et al. (2007) found that hedgerows with mulch successfully reduced soil loss from just over 100 to only 2 Mg ha^{-1} and runoff from just below 100–20 mm. Grum et al. (2017) carried out field experiment during the rainy seasons in arid and semi-arid environments and their findings showed that tied ridges or straw mulch significantly reduced runoff by 56% and 53%, respectively, and improved soil-moisture content. Ngetich et al. (2014) investigated the consequences of selected tillage practices on runoff and sediment loss under semi-arid and sub-humid environments. Their findings reported that tied ridging was the most efficient measure in reducing runoff and sediment yield in the semi-arid region. Although lots of studies have reported the effectiveness of various management measures on runoff and sediment reduction in different climatic zones (Pan et al., 2010; Baptista et al., 2015; Donjadee and Tingsanchali, 2016), few studies have actually linked these measures to rainfall variabilities, particularly when experiencing heavy rainfalls. Due to well-developed monsoon in the red-soil region of southern China, heavy rainfall, characterized by high rainfall intensity and high precipitation amounts, occurs frequently, which can lead to severer consequences of soil and water loss and further land degradation. However, the potential of management measures in combating soil erosion and nutrient loss under heavy rainfall remains unclear. Understanding the efficacy of selected measures on reducing runoff, sediment and associated nutrient loss is essential for developing further policies for soil and water conservation in the humid subtropical environments of southern China.

Hence, the objectives of this study were (1) to investigate the effects of soil management measures on controlling soil erosion in the red-soil region of southern China; (2) to investigate the effects of management measures on reducing nutrients loss under heavy rainfalls; (3) to select the optimal measures for soil and water conservation in the area.

2. Materials and methods

2.1. Study site

The field experiment was conducted in the Jiangxi Eco-science Park of Soil and Water Conservation, which is located in the Yangou watershed in De'an County of Jiangxi Province (115°42′38″ to 115°43′06″E, 29°16′37″ to 29°17′40″N). This region is characterized by a subtropical monsoon climate zone with an average temperature of 16.7 °C annually. The mean annual precipitation is 1350.9 mm, which is distributed unevenly through the year with > 70% of the total precipitation occurring from April to September. The more intense rainfall during the rainy season has led to severe soil erosion and nutrient loss in arable sloping land. The topography is generally characterized by low hills with elevations of 30–100 m. The slope across the area varies from 5° to 25°. The crop rotation of winter rapeseed (*Brassica napus*) and summer peanut (*Arachis hypogaea*) accounts for the use of sloping farmland in this district. The dominant soil type of the region is red clay soil, formed by the decomposition of Quaternary sediments (Liu et al., 2016). The soil has a depth of approximately 50 cm–150 cm with a pH of 6.67 and organic carbon matter of 8.64 g kg^{-1}. The total nitrogen (TN) concentration, total phosphorus (TP) concentration and total potassium (TK) concentration in the soil tillage layer are 0.55 g kg^{-1}, 0.31 g kg^{-1}, 15.87 g kg^{-1}, respectively. The soil contains approximately 18.34% sand (2–0.05 mm), 65.60% silt (0.05–0.002 mm) and 16.06% clay (< 0.002 mm). The soil bulk density is 1.13–1.52 g cm^{-3} in the 0–20 cm layer and 1.18–1.72 g cm^{-3} in 20–40 cm soil culturing layer.

2.2. Experimental design and agricultural practices

The field experiment was designed with five treatments: bare land as control (CK), downslope tillage (DT), downslope tillage with two hedgerows of daylily (*Hemerocallis citrina*) planted in contour (DT + HG), contour ridge tillage (CT) and straw mulch (SM) (Fig. 1). Each treatment was arranged in three 20-m-long × 5-m-wide *in-situ* runoff plots which were installed on a 10° slope. Cement walls inserted vertically 30 cm into the soil, and 20 cm above the soil surface on each side of the plots were established to disconnect adjacent plots and avoid hydrological interferences. To collect the runoff and sediments under rainfall events, a trench and two runoff collection tanks were constructed at the bottom of each plot. A water level gauge installed in