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18-year grass hedge effect on soil water loss and soil productivity on sloping cropland

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ABSTRACT

Grass hedges planted along the contour of slope cropland can greatly reduce water and soil loss, but the effect of long-term grass hedge cultivation on soil productivity is unclear. The objective of this study was to evaluate the temporal and spatial characteristics of soil thickness, soil fertility and grain yield on the slope croplands with long-term grass hedge cultivation. Four grass hedges, vetiver (*Vetiveria ziaaniodes*), false indigo (*Amsopha fruticose*), alfalfa (*Medicago sativa*) and Chinese alpine rush (*Eulaliopisi binata*), were grown for 18 years on slope croplands in the purple-soil area of Sichuan province, China. Maize was planted in the alley between the grass hedges. The results showed that the plots with grass hedges decreased runoff by 50.1%–60.7% and soil loss by 82%–91.6% compared with the control plots without grass hedges. The vetiver hedge was the most effective in reducing soil loss among the four grass hedges. The soil thickness increased 7–31 cm in the upslope position above the grass hedges and decreased 7.5–34.5 cm in the downslope position below the grass hedges compared to those at the beginning of the experiment 18 years ago. A series of less slope gradient terraces were gradually built after grass hedge planted. The gradient decrease rate was higher in the first 9 years, and the rate became lower in the next 9 years after grass hedge planted. The soil on and above the grass hedges had higher organic matter content (SOM) than the soil below the grass hedges. The maize yield had a positive correlation with SOM and soil thickness. The maize yields in the grass hedge treatments were 0%–11.3% less than that in the control. Water, nutrient and sunlight competition was the main impact factor negatively affecting the maize yield, and grass hedges retained soil thickness benefits for increasing maize yields. In addition, the grass hedges occupied space otherwise used for crop cultivation, so the plot maize yields in the grass hedge treatments were 12.7%–22.8% less than that in the control. To ensure crop production and environmental quality, it was recommended that grass hedges should be applied on slope cropland with serious soil erosion. In addition, grass species with higher soil and water conservation efficiency, smaller canopy, lower demand for water and nutrients should be selected, such as vetiver grass hedge.

1. Introduction

Soil and water loss is a serious problem in slope cropland over the world (Cerdà et al., 2010; Gao et al., 2016; Gessesse et al., 2014; Ochoa-Cueva et al., 2015). Surface soil and nutrients flow away with runoff water would lead to soil fertility degradation (Novara et al., 2016; Rodrigo Comino et al., 2016), land productivity reduction (Mwango et al., 2014; Singh et al., 2014), and environmental problems (Borrelli et al., 2013; Tian et al., 2015). Thus soil and water conservation is so important for food security and environmental sustainability (Keesstra et al., 2016a,b). Many methods have been proven to be effective in control water and soil conservation, such as grass strips, shrub and tree buffers, riparian vegetation, terraces, check dams, basins and ponds, straw mulching and no-tillage (Keesstra et al., 2016a,b; Mekonnen et al., 2015; Mekonnen et al., 2016; Prosdocimi et al., 2016).

Grass hedges, a special type of vegetative filter strip defined as dense and erect vegetation barriers made of stiff-stemmed grass that slows runoff and reduces erosion (Gilley et al., 2000; Kemper et al., 1992), are commonly used to prevent soil and water loss in sloping croplands all over the world. Research has shown that grass hedges can reduce runoff by 22%–55% and soil loss by 52%–95% (Blanco-Canqui et al., 2004a; Cullum et al., 2007; Dabney et al., 1999; Dorioz et al., 2006; Gilley et al., 2013; Mekonnen et al., 2016; Novara et al., 2013; Oshunsanya, 2013; Xiao et al., 2011), and decrease as well as the loss of

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nitrogen and phosphorous nutrients in runoff (Blanco-Canqui et al., 2004b; Gilley et al., 2013). The soil in grass hedges has the highest hydraulic conductivity compared to the croplands without grass hedges because the grass roots increase soil porosity; thus, more water infiltrates the soil, and the overland flow deceases (Agus et al., 1997; Thomas et al., 2012). The grass hedges also intercept runoff, decrease the water flow velocity and increase water ponding above the grass hedge. A decreased flow velocity and water ponding promote sediment deposition above the grass hedges (Blanco-Canqui et al., 2004a; Dalton et al., 1996). The factors that impact soil erosion in the grass hedge system include the slope gradient, grass hedges species, the interval between grass hedges, crop coverage, precipitation intensity, soil hydraulic conductivity, the initial water content, and the soil particle composition. The contributions of each factor to soil erosion vary in different studies (Lee et al., 1998; Muñoz-Carpena et al., 1999; Xiao et al., 2011).

Grass hedges greatly affected the morphology of the slope cropland. Soil erosion always happened on the upslope behind the grass hedges, and sediments were deposited on and above the grass hedges. Some less slope gradient terraces was built after the grass hedges had been planted for a long period on the slope land (Agus et al., 1997; Hien et al., 2013; Oshunsanya, 2013). The survey by Dabney et al. (2012) show progressive lowering of high elevation spots and filling of low elevation spots as contours lines more closely aligned with hedges after three years grass hedges were cultivated near to contours of the fields because sediment deposited above the hedges with lower elevation. Soil properties varied in the different position relative to grass hedges. Some studies showed that SOC, CEC and soil moisture in the upslope position above grass hedges were higher than those in the downslope position of grass hedges because soil was severely eroded in the downslope position of the grass hedges and sediments may deposit above the grass hedges as runoff was trapped (Agus et al., 1997, 1999; Hien et al., 2013). Many studies have investigated the effect of grass hedges on the cropland morphology and soil properties. However, only a few studies have focused on the effect of soil properties changes on crop yield. On one hand, grass hedges can decrease the crop yield because they compete with crops for water, nutrients and light, and the crop cultivation area will decrease because hedges occupy space (Cullum et al., 2007). On the other hand, in some high soil erosion study sites, grass hedges retained soil thickness, soil moisture and soil fertility, and grass hedges increased crop yield in these places (Dercon et al., 2006; Oshunsanya, 2013).

Many researches have shown that grass hedge can affect morphology of croplands and soil properties, and grain yield. However, these studies were conducted after hedges were planted for 1 to 5 years. Whether the morphology of croplands, soil properties and productivity will become a stable state, or how it is going after a long time is unclear. The grass hedges can be long term used after it was planted. So it was necessary to research the characteristics of the cropland morphology, soil properties and productivity for long-term grass hedge cultivation

Grass hedge is a common soil conservation method in Purple soil in the southwest China. Grain yield should be considered as well as soil and water conservation if grass hedge was applied, because of the great demand of food and limited cropland in China. Purple soil prevails in the upper reaches of the Yangtze River in the southwest China. Soil erosion is severe in the slope croplands of this region, which has led to soil fertility degradation and environmental problems in the middle and lower reaches of the Yangtze River (Lin et al., 2010). Lin et al. (2009) investigated the effect of grass hedges on soil thickness and soil properties (soil particle composition, total nitrogen (N), total phosphorous (P) and total potassium (K)) after grass hedges were planted 9 years in purple soil. However, his work had no focus on grain yield and the factors effect on yield in grass hedge system. This study improved his work at a longer time scale. The research objectives were 1) to evaluate the characteristics of water and soil loss, changes in soil thickness and fertility 18 years after grass hedges were planted and 2) to identify the grain yield characteristics and the factors affecting grain yields in the grass hedge system.

2. Material and methods

2.1. Site description

Our field experiment was carried out in the upper reaches of the Tuo River which is an important branch of the Yangtze River (104°34′12″ to 104°35′19″ E and 30°05′12″ to 30°06′44″ N with an altitude of 395 m). This region is in a subtropical monsoon climate zone with an average annual precipitation of 966 mm, of which 70% falls from June to September. The average annual temperature is 16.8 °C, with the maximum monthly temperature of 27.4 °C in July and minimum monthly temperature of 7.4 °C in January. The area is dominated by purple soil, classified as Entisol according to the US Taxonomy, which is usually 50–80 cm in depth with a relatively light texture and poor soil fertility.

2.2. Experimental designs

The trials started in November 1997, involved two experimental croplands with slope gradients of 20° and 13°. Each slope cropland had three runoff plots (7 m × 20 m each) separated by concrete plates. The 20° experimental cropland consisted of three treatments: a control (without hedgerows), vetiver and false indigo grass hedges. The 13° experimental cropland included three treatments: a control (without hedgerows), alfalfa and Chinese alpine rush grass hedges. As Fig. 1 shows, three grass hedges strips (0.5 m wide) were planted along the contour at positions of 0–0.5 m, 6.66–7.16 m and 13.3–13.8 m (the bottom of the plot was defined as the position 0 m and the top of the plot as the position 20 m).

The cropping pattern of wheat (*Triticum aestivum*)-maize (*Zea mays*)-sweet potato (*Ipomoea batatas*) was applied from 1997 to 2009. For each year, sweet potatoes were transplanted around June 16; maize was sown around April 12 and harvested around August 20; and winter wheat was sown around November 7. Alley cropping was combined with intercropping of a winter crop (wheat) and summer crops (maize and sweet potato). The detail information about the crop breed, plant

Fig. 1. Photographs of the grass hedge plots. The left picture is the vetiver grass hedge, and the right picture is the false indigo grass hedge.