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Effects of Different Land-Use Types on Soil Erosion Under Natural Rainfall in the Loess Plateau, China

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ABSTRACT

The Loess Plateau, which is located in the arid and semi-arid areas of China, experiences significant soil erosion due to intense human activities and soil erodibility. It is necessary to explore and identify the land-use types or land-use patterns that can control soil erosion and achieve certain agricultural production capabilities. This study established runoff plots with two slope gradients (5° and 15°) in north of Yan'an, one area of the Loess Plateau, with 3 single land-use types (cultivated land, CL; switchgrass, SG; and abandoned land, AL) and 2 composite land-use types (CL-SG and CL-AL). From 2006 to 2012, we continuously monitored the rainfall characteristics, runoff depth, soil loss, vegetation coverage, and soil physical properties. The results indicated a general trend in the number of runoff and soil loss events for the 5 land-use types: CL = CL-SG > CL-AL > SG> AL. The general trend for runoff depth, soil loss, their magnitudes of variation, and the slopes of rainfall-runoff regression equation was CL > CL-SG > CL-AL > SG > AL, whereas the rainfall threshold for runoff generation exhibited the opposite trend. Results of nonparametric test regarding runoff depth/EI_{30} and soil loss/EI_{30}, where EI_{30} is the product of rainfall kinetic energy and the maximum rainfall intensity over 30 min, and the runoff depth-soil loss relationship regression indicated that the effect of CL-AL was similar to that of SG; SG was similar to AL; and CL-AL, SG, and AL were superior to CL with regard to soil and water conservation. Runoff depth and soil loss significantly increased as the slope gradient increased. Runoff depth and soil loss were significantly correlated with the soil particle size composition and bulk density, respectively. The strongest significant correlations were found between runoff depth and vegetation coverage as well as between soil loss and vegetation coverage, which showed that vegetation coverage was the primary factor controlling soil erosion. Therefore, the composite land-use type CL-AL and the artificial grassland (SG) are appropriate options because both soil conservation and a certain degree of agricultural production are necessary in the study area.

Key Words: runoff depth, soil conservation, soil loss, vegetation coverage, vegetation pattern

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INTRODUCTION

Soil erosion is an important environmental issue in terrestrial ecosystems. The Loess Plateau, which is located in the arid and semi-arid areas of China, experiences significant soil erosion due to intense human activities and soil erodibility. From 1955 to 1989, this region endured more than 50 t ha^{-1} year^{-1} of soil erosion, which accounts for 42% of its total area (Wang and Jiao *et al.*, 2002). This intense soil erosion threatens the ecological safety and agricultural sustainability of the region (Lü *et al.*, 2007). Furthermore, the sediment that discharges into the Yellow River elevates the riverbed in the lower reaches of the river and increases the risk of flooding. Therefore, the mode of soil erosion control has become an important subject with regard to the construction of the ecological environment in the Loess Plateau.

Vegetation coverage is an important factor with regard to soil erosion control (Cinnirella *et al.*, 1998; Zhang *et al.*, 2004; Zheng, 2006; Wei *et al.*, 2007; Zhao *et al.*, 2013). Vegetation can reduce the direct effect of raindrops on the soil (Durán Zuazo *et al.*, 2008), reduce surface runoff (Puigdefábregas, 2005; Durán Zuazo *et al.*, 2006), alleviate runoff denudation of the soil (Li *et al.*, 2005), enhance the organic matter content in the soil, and increase the infiltration rate of water (Puigdefábregas *et al.*, 1999). The physical barrier effect of vegetation influences the transportation of sediments on the surface (Martínez Raya *et al.*, 2006). Numerous

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studies concerning the effect of vegetation on soil erosion focus not only on a single-vegetation land use type such as woodland (Kateb *et al.*, 2013), shrubland (Garcia-Estringana *et al.*, 2013), abandoned land (Liu Y *et al.*, 2012), pasture (Jiao and Wang, 2001; De Koff *et al.*, 2011), and cultivated land (Sasal *et al.*, 2010), but also on a mosaic of vegetation types. A mosaic of vegetation can be naturally formed (Arnau-Rosalén *et al.*, 2008) and artificially planted (Xiao *et al.*, 2011; Zhang *et al.*, 2012). The vegetation coverage and mosaic pattern influence the connectivity of runoff (Mayor *et al.*, 2008) and form areas of soil erosion and sediment deposition on the surface. Therefore, the continuity of vegetation coverage is crucial for protecting the soil from erosion and the presence of small uncovered areas within woodland can determine a strong reduction of soil conservation effect (Porto *et al.*, 2009). Among the various factors that affect soil erosion, vegetation coverage can be artificially altered by adjusting land-use type (Chen *et al.*, 2003).

In 1999, China began to implement a policy seeking to return farmland to forest and grassland. After more than 10 years of vegetation restoration, the vegetation coverage in the Loess Plateau improved (Zhang *et al.*, 2011; Lü *et al.*, 2012). However, trees with poor growth (referred to as little old trees) are common in north of Yan'an, one area of the Loess Plateau (Wang *et al.*, 2004; Zhao and Li, 2005) because these trees consume substantial quantities of water under inadequate rainfall, causing soil desiccation and inhibiting tree growth (Jin *et al.*, 2011). Wang *et al.* (2012) and Sun *et al.* (2014) indicated that the grassland in the Yanhe watershed of the Loess Plateau exhibited greater soil moisture retention capability than the woodland. Although natural forests are superior to grassland with regard to soil conservation, the soil conservation abilities of plantation forests are frequently worse than those of natural grassland due to poor growth or the incomplete community structures of plantation forests (Nunes *et al.*, 2011; Wang *et al.*, 2013).

Due to the large population and comparatively limited amount of land in the Loess Plateau, the complete abandonment of cultivated land on slopes is unrealistic. By arranging artificial grasslands or combining cultivated lands and grasslands to form a crop-grassland vegetation mosaic, we can control soil erosion and achieve certain agricultural production capabilities. However, few studies have explored the effect of a crop-grass vegetation mosaic on soil conservation under natural rainfall in the Loess Plateau. Kang *et al.* (2007) and Zhang *et al.* (2012) used artificial rainfall to study the effect of the grassland vegetation pattern on soil conservation. Switchgrass (*Panicum virgatum*), originating in North America, has significant developmental potential as an energy plant. Switchgrass was introduced to the Loess Plateau in the 1980s and numerous studies have been performed on its physiological and ecological characteristics, cultivation management, and biomass fuel quality (Xu *et al.*, 2005; Liu J *et al.*, 2012). However, studies regarding the effects of switchgrass on the water and soil conservation are limited. Ichizen *et al.* (2005) and Jin *et al.* (2012) conducted a short-term study on the water and soil conservation, treating switchgrass as an artificial grassland under natural rainfall.

The Loess Plateau is characterized by a large population, limited land area, and the acute conflict between people and the land. It is necessary to explore and identify the land-use types or land-use patterns that can control soil erosion and achieve certain agricultural production capabilities. Therefore, we continuously observed the vegetation coverage, soil properties, runoff depth, and soil loss associated with different land-use types under natural rainfall conditions in the Loess Plateau. Based on the above observations, we compared the water and soil conservation performances under different land-use types to provide the theoretical basis for exploring a suitable type for the Loess Plateau.

MATERIALS AND METHODS

Study area

The study area was located at the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences (109° 19′ 23″ E, 36° 51′ 30″ N), in Ansai County, Yan'an City, Shaanxi Province (Fig. 1). The Ansai Research Station is located in the loess hill and gully region of the central Loess Plateau. This area is covered by a thick mantle of loess, which is an erosion-prone, fine silt soil. Characterized by a warm, temperate, semi-arid, and continental monsoon climate with distinct wet and dry seasons, this area have multi-year average, maximum, and minimum temperatures of 8.8, 37.3, and −18.5 °C, respectively. The average annual precipitation is 505.3 mm. The rainfall shows high seasonal variability: more than 60% of the annual precipitation occurs between July and September. The sunlight in this area is adequate: the multi-year average sunshine duration is 2 446.6 h, the multi-year average sunshine percentage is 55%, and the average frost-free period extends 184 d.