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Research Paper

Effects of landscape positions on soil resistance to rill erosion in a small catchment on the Loess Plateau

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Landscape position has significant effects on soil properties and plant roots, and thus probably affects soil resistance to rill erosion, reflected by rill erodibility and critical shear stress. However, the potential effects of landscape positions on soil resistance to rill erosion are still unclear. Therefore, this study was conducted to investigate the spatial variations in soil resistance to rill erosion under different landscape positions, and to identify the main factors controlling these variations in a small catchment of the Loess Plateau. 540 undisturbed soil samples were collected from 18 typical sampling sites of natural succession grassland under six landscape positions and subjected to scour under different flow shear stresses. The results showed that landscape position significantly affected the spatial variation of rill erodibility. The mean rill erodibility decreased gradually from the top of ridge to footslope and increased linearly with elevation. Significant differences were detected in rill erodibility between three grass species. No significant difference was found in critical shear stress between six landscape positions. Soil erosion and soil water content dominated the regular spatial changes of soil properties and root mass density along six landscape positions. All of these factors collectively resulted in the regular decrease of rill erodibility from the top of ridge to footslope. A negative relationship was identified between critical shear stress and clay content. Rill erodibility could be satisfactorily estimated by the median soil grain size, soil cohesion, water stable aggregate and root mass density.

1. Introduction

The Loess Plateau, with a total area of 6.24×10^5 km^2, is located in northwestern China. It is covered with highly erodible aeolian deposits and has a semiarid to sub-humid climate (Zhang, Liu, Tang, & Zhang, 2008). Highly erodible soil, heavy storm, steep slope, poor vegetation cover and improper land use cause the Loess Plateau to be one of the most erodible areas in the world (Fu, Gulinck, & Masum, 1994;

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Nomenclature

D_c	soil detachment capacity (kg m^{-2} s^{-1})
K_r	rill erodibility (s m^{-1})
τ_c	critical shear stress (Pa)
TR	top of ridge
UR	upper ridge slope
MR	middle ridge slope
LR	lower ridge slope
GB	gully bed
FT	footslope
τ	flow shear stress (Pa)
SB	*Stipa bungeana Trin.*
PA	*Poa annua* L
BS	*Blysmus sinocompressus Tang et Wang*
EL	elevation (m)
SD	standard deviation
CV	coefficient of variation
D_{50}	mean soil grain size (mm)
BD	bulk density (kg m^{-3})
Coh	cohesion (kPa)
WSA	water stable aggregate (0–1)
SOM	soil organic matter (g kg^{-1})
RMD	root mass density (kg m^{-3})
R^2_a	adjusted coefficient of determination

Zhang & Liu, 2005), with the mean annual erosion rate in the most regions varying from 5000 to 10,000 Mg km^{-2} year^{-1}. In some areas of the Huangpuchuan watershed, soil erosion rate can reach as high as 59,700 Mg km^{-2} year^{-1} (Shi & Shao, 2000). Approximately 16.4 × 10^8 Mg sediments are transported to lower reaches of the Yellow River every year (Zhang et al., 2008). Such serious soil erosion leads to severe soil deterioration in the middle reaches of the Yellow River (the Loess Plateau) and high flood risk in the lower reaches. Controlling soil erosion in the Loess Plateau has always been one of the critical issues for Chinese government.

Soil erosion involves three sub-processes of soil detachment, sediment transport, and deposition (Zhang et al., 2008). Soil detachment is the process of dislodgment of soil particles from the soil matrix at particular location on the soil surface (Owoputi & Stolte, 1995). According to the first-order detachment-transport coupling equation proposed by Foster and Meyer (1972), soil detachment rate decreases with sediment load. The soil detachment capacity (D_c) appears in clear water when sediment load is zero (Govers, Giménez, & Oost, 2007; Nearing, Bradford, & Parker, 1991; Zhang, Liu, Tang, & Zhang, 2009). D_c can be measured directly via flume test to estimate rill erodibility (K_r) and critical shear stress (τ_c) (Nearing, Foster, Lane, & Finkner, 1989). Both of them describe soil resistance to rill erosion (Knapen, Poesen, Govers, & De Baets, 2008), and are widely used as input parameters in the process-based erosion models, such as CREAMS (Foster, Lane, Nowlin, Laflen, & Young, 1981), WEPP (Nearing et al., 1989) and EGEM (Woodward, 1999). In recent decades, many studies have demonstrated that soil resistance to rill erosion (K_r and τ_c) is affected by soil properties, plant roots, land uses, and agricultural practices (Ciampalini & Torri, 1998; Knapen, Poesen, Govers, Gyssels, & Nachtergaele, 2007).

Soil properties (e.g. soil texture, bulk density, soil water content, soil cohesion, water stable aggregate and soil organic matter) have great effects on soil resistance to rill erosion (Geng, Zhang, Li, & Wang, 2015; Gilley, Elliot, Laflen, & Simanton, 1993; Govers & Loch, 1993; Knapen, Poesen & De Baets, 2007). Sheridan, So, Loch, and Walker (2000) reported low rill erodibility (K_r) for clay and silt soils, while the soil particle size greater than silt but smaller than 10 mm had high rill erodibility. Although Smerdon and Beasley (1961) reported a positive relationship between clay content and τ_c, Torri, Sfalanga, and Chisci (1987) showed no correlation existed between τ_c and clay content. Sand content was negative related toτ_c in the study of Auzet, Boiffin, Papy, Ludwig, and Maucorps (1993). Greater soil bulk density was attributed to greater soil consolidation, thus K_r decreased with the increase of soil bulk density and τ_c showed an increasing trend with the increase of soil bulk density (Bennett, Casalí, Robinson, & Kadavy, 2000; Knapen, Poesen, Govers, et al., 2007; Yu, Zhang, Geng, & Sun, 2014). Soil water content determines the cohesion between soil particles, Nachtergaele and Poesen (2002) found that the initial soil water content could well explain the spatial and temporal variations of soil resistance to ephemeral gully erosion. Soil cohesion and water stable aggregate, to some degree having the similar boding mechanisms, are thought as the most suitable parameters for simulating soil resistance to rill erosion (Fattet et al., 2011; Léonard & Richard, 2004; Wang et al., 2013). Geng et al. (2015) demonstrated K_r increased with the increase of soil cohesion and water stable aggregate and τ_c decreased with the decrease of soil cohesion and water stable aggregate. Soil organic matter acts as a bonding matter between soil particles and thus reduces soil resistance to rill erosion (Knapen, Poesen, Govers, et al., 2007). Li, Zhang, Geng, and Wang (2015a) found K_r decreased with the increase of soil organic matter.

Soil resistance to rill erosion is greatly influenced by plant root systems (Vannoppen, Vanmaercke, De Baets, & Poesen, 2015). The effect of plant roots on erosion is the result of the complex biophysical and biochemical reactions (Simon & Collison, 2002; Zhang, Tang, Sun, & Zhang, 2014). Root length density and mass density are the most commonly used parameters to characterise the erosion-reducing potential of root systems (De Baets & Poesen, 2010; De Baets, Poesen, Gyssels, & Knapen, 2006). Generally, rill erodibility (K_r) decreases exponentially with root length density or root mass density (Geng et al., 2015). However the influence of plant roots on critical shear stress (τ_c) remains ambiguous (Mamo & Bubenzer, 2001). In addition, root architecture also influences soil resistance to rill erosion. The results of De Baets, Poesen, Knapen, and Galindo (2007) indicated that fibrous roots reduced the erosion rate to a greater extent than tap roots. In addition, land use exerts great influence on soil resistance to rill erosion by affecting soil properties and plant roots. Li et al. (2015a) studied the effect of land use on rill erodibility, and found the ratios of crop land to roads, orchards, shrub land, woodland, grassland, and wasteland was 1.74, 9.17, 11.65, 26.34, 28.88, and 42.57 respectively.

In a small catchment, landscape position plays an important role in the spatial variations of soil properties, by