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Research Paper

Rill erodibility as influenced by soil and land use in a small watershed of the Loess Plateau, China

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Land use can significantly affect soil properties, root systems, and tillage practices, and hence probably influence rill erodibility (K_r) considerably. Nevertheless, there is little quantitative research on the effects of land use on K_r. The objectives of this study were to evaluate the influence of land use on K_r, quantify its potential influencing factors, and develop a regression model to estimate K_r in a small Loess Plateau watershed. Undisturbed samples were collected from four different land uses on red Loess soil and seven different land uses on yellow Loess soil. Soil detachment capacity by overland flow was measured in a sand-glued hydraulic flume under six different shear stresses (5.59–18.31 Pa) to determine K_r. The results indicated that K_r was affected by soil type significantly and the average K_r of yellow Loess soil was 1.5 times greater than that of red Loess soil. K_r was also significantly influenced by land use. For the red Loess soil, cropped land had the maximum K_r and followed by orchards, shrub land, and grassland. For the yellow Loess soil, cropped land also had the maximum K_r, which was 1.74, 9.17, 11.65, 26.34, 28.88, and 42.57 times greater than those of roads, orchards, shrub land, woodland, grassland, and wasteland, respectively. K_r increased with silt content, and decreased with soil cohesion, water stable aggregate, soil organic matter, and root mass density. A nonlinear regression showed that K_r could be estimated well ($NSE = 0.87$) by silt content, soil cohesion, water stable aggregate, and root mass density in the Loess Plateau.

1. Introduction

Soil erosion has been widely considered as a major environmental threat to sustainable development and the productive capacity of agriculture since it adversely influences soil quality by reducing soil depth, water-holding capacity, nutrients, and soil biota (Capra & Scicolone, 2002; Pimentel et al., 1995). Erosion involves the processes of soil detachment, sediment transport, and deposition, and can be divided into

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Nomenclature

D_c	soil detachment capacity (kg m^{-2} s^{-1})
CH	soil cohesion (kPa)
K_r	rill erodibility (s m^{-1})
$Silt$	silt content (0–1)
τ	shear stress (Pa)
RD	root mass density (kg m^{-3})
τ_c	critical shear stress (Pa)
WSA	water-stable aggregate (0–1)
WRB	world reference base for soil resources
SSS	United States Department of Agriculture soil classification

interrill, rill, and ephemeral gully erosions on hillslope (Govers, Giménez, & Van Oost, 2007; Meyer & Wischmeier, 1969). Rill erosion, defined as the dominant process of detachment and transport by overland flow in rill areas, is an important sediment source and channel for sediment transport (Gyssels, Poesen, Nachtergaele, & Govers, 2002; Nachtergaele & Poesen, 2002). The Loess Plateau of China has probably the most severe erosion in the world (Cao, Zhang, & Zhang, 2009; Fu et al., 2009; Yu, Zhang, Geng, & Sun, 2014), and rill erosion accounts for approximately 70% of the total erosion from upland areas (Zheng & Tang, 1997). Therefore, there is a strong need to understand the mechanisms of rill erosion to develop erosion models suitable for the Loess Plateau.

In most of the process-based erosion models, rill erodibility is an important input parameter for estimating rill erosion rate. It reflects the soil resistance to detachment by overland flow. In the Water Erosion Prediction Project (WEPP) model (Flanagan & Nearing, 1995), rill erodibility is defined as the increase in soil detachment capacity caused by per unit increase in shear stress of the flowing water:

$$D_C = K_r(\tau - \tau_c) \quad (1)$$

where D_c is the soil detachment capacity, i.e. the detachment rate of clear water (kg m^{-2} s^{-1}), K_r is the rill erodibility (s m^{-1}), τ is the flow shear stress (Pa), and τ_c is the critical shear stress (Pa). When the measured detachment capacity is plotted against the flow shear stress, rill erodibility can be determined from the slope of the regression linear line (Flanagan & Nearing, 1995). Rill erodibility is influenced by many factors such as soil properties, root systems, and tillage practices (Knapen, Poesen, Govers, Gyssels, & Nachtergaele, 2007).

Rill erodibility is affected greatly by soil properties, e.g. type, texture, bulk density, cohesion, aggregate stability, and organic matter. Ghebreiyessus, Gantzer, Alberts, and Lentz (1994) found that rill erodibility was influenced by soil bulk density significantly and found that the measured K_r increased by 470% when soil bulk density decreased from 1400 to 1200 kg m^{-3}. In the WEPP model, K_r was closely related to soil texture and rill erodibility of clay loam soil was less than those of loamy sand and silt loam soils (Flanagan & Nearing, 1995). Rapp (1998) demonstrated that rill erodibility decreased with clay content. Knapen, Poesen, and De Baets (2007) revealed that rill erodibility decreased as bulk density and organic matter increased, and a regression equation was developed to simulate the seasonal variation in K_r (Knapen, Poesen, Govers, & De Baets, 2008).

Rill erodibility is considerably influenced by root systems. The effect of root systems on K_r can be attributed to physically binding effect and chemically exudates-bonding effect (Wang et al., 2014). The function of root systems reducing soil detachment relates to root diameter, root length or mass density, root area ratio, and root architecture. Li, Zhu, and Tian (1991) found that the ability of plant root to decrease soil scouring mainly depended on the number of fine roots (<1 mm in diameter) per unit soil volume. Rill erodibility decreases as an exponential function of root length or mass density (Gyssels, Poesen, Bochet, & Li., 2005; Mamo & Bubenzer, 2001a, 2001b; Zhang, Tang, Ren, & Zhang, 2013). De Baets, Poesen, Gyssels, and Knapen (2006) indicated that rill erodibility declined with an increase in root area ratio. Soil detachment capacity by overland flow (and thus K_r) is closely related to root architecture. The effect of fibrous root system is greater than that of tap root system (De Baets & Poesen, 2010; De Baets, Poesen, Knapen, & Galindo, 2007; Zhang et al., 2013).

Besides soil properties and root systems, rill erodibility is also strongly influenced by tillage practices, which mainly relies on the degree of disturbance caused by tillage operations (West et al., 1992). Rill erodibility can be assumed to be the highest immediately after tillage since soil is loose and easily detached (Franti, Laflen, & Watson, 1985). Tillage practices also can modify the soil aggregate stability via changes in soil biology, and such structural changes exert substantial effect on soil erosion or rill erodibility (García-Orenes et al., 2012). Knapen, Poesen, Govers, et al. (2007) compiled the data base of the WEPP model and found that no-tillage soils would have considerably lower rill erodibility than those of conventionally tilled soils or soils with reduced tillage. Zhang, Tang, and Zhang (2009) indicated that all tillage practices, i.e. planting, ploughing, weeding, and harvesting, disturbed the soil surface to form a loose erodible layer, leading to an increase in rill erodibility.

Land use can significantly affect soil properties, root systems, and tillage practices. Soil bulk density, soil cohesion, aggregate stability, and organic matter depend on land use (Celik, 2005; Cerdà, 1998; Islam & Weil, 2000). Root systems vary considerably with land use and plant species (De Baets & Poesen, 2010; Gyssels et al., 2005). The tillage practices of different crops and rotation are quite different (Kanpen, Poesen, & De Baets, 2007; Mamo & Bubenzer, 2001a, 2001b; Zhang et al., 2009). These variations in soil properties, root systems, and tillage practices associated with land use probably have a significant effect on rill erodibility. Nevertheless, the effect of land use on rill erodibility is not yet fully understood, especially in the Loess Plateau where serious erosion is mainly caused by improper land use (Fu et al., 2009). Therefore, it is imperative to quantify the effects of land use on rill erodibility for soil erosion prediction and its control under different conditions.

Hitherto, there has been little quantitative research on the effects of land use on rill erodibility, and the influencing factors and their effects are still not fully quantified. Mamo and Bubenzer (2001a) found that maximum rill erodibility