Catena 124 (2015) 9–17

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Land use impacts on soil detachment capacity by overland flow in the Loess Plateau, China

Zhen-Wei Li [a,b], Guang-Hui Zhang [a,c,*], Ren Geng [c], Hao Wang [c], X.C. Zhang [d]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] School of Geography, Beijing Normal University, Beijing 100875, China
[d] USDA-ARS Grazinglands Research Laboratory, EL Reno, OK, USA

ARTICLE INFO

Article history:
Received 5 July 2014
Received in revised form 14 August 2014
Accepted 27 August 2014
Available online 16 September 2014

Keywords:
Soil erosion
Detachment capacity
Soil type
Land use
The Loess Plateau

ABSTRACT

Land use and its adjustment may greatly affect soil detachment process by overland flow via altering soil properties, root systems, and tillage operations, but few studies were performed to quantify their effects on soil detachment in the Loess Plateau. This study was conducted to investigate the potential effects of land use on soil detachment capacity by overland flow (D_c, kg m^{-2} s^{-1}) using natural undisturbed soil samples taken from four different land uses on the red loess soil and six different land uses on the yellow loess soil, and to quantify the relationships between soil detachment capacity and hydraulic parameters, soil properties, and root systems in the Loess Plateau. The collected samples were tested in a 4.0 m long, 0.35 m wide hydraulic flume under six different shear stresses (5.51–16.59 Pa). The result showed that both soil type and land use had significant effects on D_c. For two tested soils, the mean D_c of the yellow loess soil was 1.49 times greater than that of the red loess soil. For the red loess soil, D_c of cropland was the maximum, which was 5.57, 5.85, and 34.08 times greater than those of shrub land, orchard, and grassland, respectively. For the yellow loess soil, cropland was much more erodible than other five land uses. On average, the ratios of the cropland D_c to those of orchard, shrub land, woodland, grassland, and wasteland were 7.14, 12.29, 25.78, 28.45, and 46.43, respectively. The variability of D_c under different land uses was closely related to soil properties, root systems, and tillage operations. Soil detachment capacity was positively related to silt content, and inversely related to sand content, cohesion, water stable aggregate, aggregate median diameter, organic matter, and root density. The measured detachment capacity could be well estimated by measurable parameters of stream power, slope gradient, soil bulk density, median diameter, silt content, cohesion, and root density (Nash–Sutcliffe efficiency = 0.89).

1. Introduction

Soil detachment, defined as the soil particles being separated from the soil matrix at a particular location on the soil surface by erosive agents (Wang et al., 2014a; Zhang et al., 2003), is a key process affecting soil erosion since it determines the amount of sediment that is potentially transferred to surface water bodies. Soil detachment rate is expressed as the sediment amount detached per unit area per unit time (Zhang et al., 2009a). With increase in sediment concentration in flowing water, more energy is used for sediment transport, which causes a decrease in soil detachment rate (Lei et al., 2002; Zhang et al., 2009b). The maximum soil detachment rate occurs in the case of clear water and it is termed as soil detachment capacity (Nearing et al., 1991). Soil detachment capacity is a key parameter in many process-based erosion models such as the Water Erosion Prediction Project (WEPP) model (Nearing et al., 1989). Therefore, quantifying D_c under different conditions is pivotal to calibrate and validate the process-based erosion models.

Soil detachment capacity by overland flow is influenced by various factors such as flow hydraulics, soil properties, root systems, tillage operations, and land use (Knapen et al., 2007a; Scherer et al., 2012). For a given soil, flow hydraulics (e.g. discharge, slope gradient, flow depth, and velocity) control the process of detachment (Govers, 1992; Zhang et al., 2003). Soil detachment capacity increases with flow discharge and slope gradient, and is more sensitive to discharge than slope gradient. Shear stress and stream power are commonly used to simulate erosion processes in process-based models (Nearing et al., 1991). However, some studies indicate that stream power is better than shear stress to predict soil detachment capacity (Cao et al., 2009; Zhang et al., 2003).

---

* Corresponding author at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China. Tel.: +86 13671086156; fax: +86 10 58806955.
E-mail address: ghzhang@bnu.edu.cn (G.-H. Zhang).

http://dx.doi.org/10.1016/j.catena.2014.08.019
0341-8162/© 2014 Elsevier B.V. All rights reserved.

Soil detachment capacity is strongly influenced by soil properties since it occurs on the interface of flowing water and soil (Zhang et al., 2009a). D_c decreases with increases in clay content, bulk density, cohesion, water stable aggregate, aggregate median diameter, organic matter content, and biological crust (Ghebreiyessus et al., 1994; Knapen et al., 2007a, 2007b; Wang et al., 2013; Zhang et al., 2008), but increases with silt content and soil moisture (Knapen et al., 2007a; Nachtergaele and Poesen, 2002). In a flume experiment using disturbed soil samples, Ciampalini and Torri (1998) found that soil detachment capacity could be predicted by clay content, bulk density, shear strength, and aggregate median diameter. For undisturbed soil samples, De Baets and Poesen (2010) showed that bulk density and soil moisture could be used to estimate D_c for both bare and rooted topsoils.

Plant root is another important factor affecting soil detachment capacity by overland flow via its physically binding effect and chemically bonding effect to enhance soil stability and resistance to flowing water erosion (Wang et al., 2014b). Root systems also play a crucial role to improve soil strength, thereby reducing the erodibility of topsoil (De Baets et al., 2011). Soil detachment capacity decreases exponentially with increasing root mass density (De Baets et al., 2006; Zhang et al., 2013). Root architecture also has a great influence on the role of roots to control soil erosion by flowing water. Fibrous root systems are more powerful to reduce soil detachment than tap root systems (De Baets et al., 2007).

Tillage operations (e.g. planting, plowing, hoeing, and harvesting) disturbed land surface to form a loose erodible layer and hence promotes soil detachment capacity (Zhang et al., 2009a). With time elapsing after tillage, the topsoil consolidates and is difficult to detach by flowing water due to the effect of consolidation, resulting a decrease in soil detachment capacity (Knapen et al., 2007a; Zhang et al., 2009a). In a field study, King et al. (1995) found that soil detachment rate was much lower in a no-till soil than that in a conventional-till soil. In eroding channels with high-discharge overland flow, Franti et al. (1999) demonstrated that soil detachment rates from tilled channels were an order of magnitude greater than those from no-till channels.

Many studies showed that land use has a profound influence on soil erosion (García-Ruiz, 2010; Podwojewski et al., 2008). Among the factors related to the intensity and frequency of flowing water erosion, land use is considered as the most important factor influencing soil detachment, even exceeding the influence of rainfall intensity and slope gradient in some circumstances (García-Ruiz, 2010). Soil detachment capacity by overland flow may vary widely under different land uses (Ciampalini and Torri, 1998; Knapen et al., 2007a), yet few studies have been conducted to quantify the differences. The study conducted by Zhang et al. (2008) found that soil detachment capacity was affected by land use considerably. The D_c of cropland was the maximum and was 2.05, 2.76, 3.32, and 13.32 times greater than those of grassland, shrub land, wasteland, and woodland, respectively.

As one of the severely eroded region, the Chinese Loess Plateau probably has the most severe erosion in the world, which directly restricts the ecological security and the social economical sustainability in this area (Fu et al., 2000). The principal reason for such serious erosion in the Loess Plateau is low vegetation cover as a result of inappropriate land use (Fu et al., 2000). Therefore, the Chinese government has paid great attention to control soil erosion in this region. The long-term, policy-driven “Grain for Green” project implemented in 1999 is mainly to plant trees, grass, or to convert croplands to grasslands under natural vegetation restoration to reduce soil erosion and improve soil quality in the Loess Plateau (Fu et al., 2000, 2006). This project must lead to great changes in land use, and thus results in potential changes in soil detachment process.

Land use adjustment certainly causes, at least at a small watershed scale, many changes in soil properties (Celik, 2005; Islam and Weil, 2000), root systems (Burylo et al., 2012; Pierret et al., 2007), and tillage operations (Knapen et al., 2007a; Zhang et al., 2009a). Those changes affect soil detachment diversely as mentioned above. However, the impact of land use on soil detachment capacity is not yet fully quantified, especially in a landscape where the complex combinations of soil type, land use, and plant species could certainly affect soil detachment capacity by overland flow. The objectives of this study were to investigate the potential effects of land use on soil detachment capacity by overland flow using undisturbed soil samples collected from the red loess and yellow loess soils subjected to detach under different hydraulic conditions, and to quantify the relationships between soil detachment capacity and hydraulic parameters, soil properties, and root systems in a Loess Plateau catchment.

2. Materials and methods

2.1. Study area

Experiments were carried out in the Zhifanggou watershed in Ansai County, Shaanxi Province, China (36°46′28″–36°46′42″N, 109°13′46″–109°16′03″E, altitude 1010–1431 m) (Fig. 1). The watershed is 8.27 km^2 in size and is characterized by a semiarid continental climate, with the mean annual temperature and precipitation of 8.8 °C and 505 mm. The geomorphology exhibits the characteristics of a main valley with a gully density of 4.20 to 8.06 km km^{-2} (Fu et al., 2006). The soil, developed from loess parent material, has a homogeneous silt loam texture, and is weakly resistant to erosion (Fu et al., 2006). The yellow loess soil and red loess soil are two main soil types in the watershed and their major properties are shown in Table 1. Due to long-term intensive human activities, most natural vegetation has been destroyed. Current principal land uses are cropland, orchard, shrub land, woodland, grassland, and wasteland. The major plant species of different land uses are listed in Table 1.

2.2. Sampling site

After a completely watershed survey, the sampling sites were stratified by soil types, land uses, and plant species. Altogether 23 sampling sites (including 6 land uses, 23 plant species) and 6 sampling sites (including 4 land uses, 6 plant species) were chosen for the yellow loess soil and red loess soil (Table 1, Fig. 1). Some weeds grew in shrub land and woodland, but few or none in cropland and orchard. Tillage operations such as planting, plowing, hoeing, and harvesting were operated in croplands, while no any tillage operations were utilized in shrub land, woodland, grassland, and wasteland. In orchard, weeds were hoed once in the jujube on yellow loess soil. A thin layer of soil biological crust was developed in the jujube orchard on red loess soil and on the YWaAA wasteland site (Table 1) when soil samples were taken, which probably had some effect on soil detachment capacity measurement.

2.3. Soil sampling

Undisturbed soil samples were collected from surface soil using steel rings with a diameter of 10 cm and a height of 5 cm from August to September 2013 for soil detachment capacity measurement. Detailed information of soil sampling procedures could be found in previous papers (Zhang et al., 2003, 2008, 2009a). The procedures were described briefly here. The sampling procedures were almost the same for all sites except for the treatment of weeds. In shrub land, woodland, grassland, and wasteland, the weeds were clipped carefully near the soil surface with a pair of scissors, and thus some roots existed in soil samples. In cropland and orchard, soil samples were collected from flat patches, and few roots were taken within soil samples. When sample was taking, the steel ring was slowly pressed down into the soil, and was excavated carefully after the top rim of the ring was flushed with the soil surface. Then the core bottom was trimmed to level with the ring rims, and both ends were covered with cotton cushions and lids to avoid disturbance during sample transport. To ensure the same soil moisture, the soil cores were saturated for 8 h in a container with a