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Research Paper

Temporal variation in soil detachment capacity by overland flow under four typical crops in the Loess Plateau of China

Yao-chuang Yu [a,b], Guang-hui Zhang [a,c,*], Ren Geng [c], Long Sun [a,b]

[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] Graduate University of Chinese Academy of Sciences, Beijing 100049, China
[c] School of Geography, Beijing Normal University, Beijing, 100875, China

ARTICLE INFO

Article history:
Received 19 September 2013
Received in revised form
20 March 2014
Accepted 6 April 2014
Published online

Keywords:
Soil detachment capacity
Temporal variations
Soil consolidation
Root growth
Tillage practices

Accurate estimation of the temporal variation in soil detachment capacity (D_c, kg m^{-2} s^{-1}) by overland flow and its potential influencing factors is critical to predict rill erosion. However, detailed information on the temporal variation in D_c remains limited for the cultivated lands in the Loess Plateau of China. This study was conducted to investigate the temporal variations in soil detachment capacity by overland flow using undisturbed topsoil samples collected from four typical crops (maize, millet, soybean, and potato) and to further identify the potential factors causing these changes during one growing season from early April to late September in 2012 in the Loess Plateau of China. The results showed that the measured mean D_c was greatest for potato, followed by maize, soybean, and millet. Soil detachment capacity for each crop fluctuated significantly over time with a similar pattern of temporal variation. The temporal variations of soil detachment capacity were affected by tillage practices, soil consolidation, water-stable aggregates (WSA), and root growth. Soil detachment capacity of four crops could be estimated using flow shear stress, soil cohesion (SC), and root density (RD) (Nash–Sutcliffe model efficiency = 0.89). Further studies are needed to investigate the potential effects of root architecture on soil detachment capacity by overland flow under different conditions.

1. Introduction

Soil detachment is the dislodging of soil particles from the soil matrix by erosive agents (Zhang, Tang, & Zhang, 2009), providing loose, non-cohesive sediment for subsequent transport and deposition. Soil detachment capacity by overland flow is defined as the maximum soil detachment rate when sediment concentration in inflow is zero, which refers to soil detachment ability with clear water under a specific

* Corresponding author. 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.
E-mail address: ghzhang@bnu.edu.cn (G.-h. Zhang).
http://dx.doi.org/10.1016/j.biosystemseng.2014.04.004
1537-5110/

Nomenclature

D_c	soil detachment capacity (kg m^{-2} s^{-1})
SMC	soil moisture content (%)
DBD	dry bulk density (kg m^{-3})
WSA	water-stable aggregates (%)
RD	root density (kg m^{-3})
RLD	root length density (m m^{-3})
SC	soil cohesion (kPa)
RSA	external root surface (m^2 m^{-3})
V	volume (m^3 m^{-3})
FR%	percentage of fine roots (%)
D	mean root diameter (mm)

hydraulic condition. In the well-known Water Erosion Prediction Project (WEPP) model, soil detachment rate in rills is computed using soil detachment capacity, sediment transport capacity, and flow sediment load based on the assumed linear function (Foster & Meyer, 1972; Nearing, Foster, Lane, & Finkner, 1989). Soil detachment by overland flow is controlled by various factors, i.e. hydro-meteorological conditions, soil properties, land use, and tillage practices (Scherer, Zehe, Träbing, & Gerlinger, 2012). Flow hydraulics and soil properties have often been used as two primary factors to simulate soil detachment capacity. For a given soil, it is closely related to hydraulics of overland flow, for example, flow rate, slope gradient, depth, velocity, friction, and sediment load (Cochrane & Flanagan, 1997; Govers et al., 1990; Nearing, Simanton, Norton, Bulygin, & Stone, 1999; Zhang, Liu, Liu, He, & Nearing, 2003; Zhang, Liu, Nearing, Huang, & Zhang, 2002; Zhang et al., 2009). Soil detachment capacity increases with flow discharge and slope gradient, and can be well predicted by a combination of them (Nearing et al., 1999; Zhang et al., 2002, 2003). As sediment load increases, soil detachment rate decreases linearly due to the feedback relationship between the processes of soil detachment and sediment transport (Zhang et al., 2009).

Soil detachment by overland flow occurs at the interface between flow and soil, and therefore it is strongly affected by soil properties. Generally, it increases with soil silt content and moisture, but decreases with soil clay content, bulk density, aggregate content, soil cohesion (SC), soil strength, consolidation, and organic matter content (Ghebreiyessus, Gantzer, Alberts, & Lentz, 1994; Knapen, Poesen, Govers, Gyssels, & Nachtergaele, 2007; Morgan et al., 1998; Nearing, West, & Brown, 1988; Zheng, Huang, & Norton, 2000). However, many of those soil properties fluctuate greatly over time, which can certainly lead to temporal variation in soil detachment (Knapen, Poesen, & De Baets, 2007; Zhang et al., 2009). Previous limited studies have shown that the temporal variation in soil detachment capacity by overland flow was only influenced by some of soil properties (Knapen, Poesen, Govers, Gyssels, & Nachtergaele, 2007; Zhang et al., 2009), i.e. soil moisture (Nachtergaele & Poesen, 2002), soil sealing and crusting, and freeze and thaw cycle (Bryan, 2000; Van Klaveren & McCool, 1998). For grassland, the temporal variation in soil detachment capacity by overland flow may also be affected by root growth (De Baets, Poesen, Gyssels, & Knapen, 2006; Mamo & Bubenzer, 2001a; Zhang et al., 2009), and decomposition of plant residue (Brown, West, Beasley, & Foster, 1990).

The plant root system has a significant effect on the soil detachment process by overland flow (De Baets & Poesen, 2010; Gyssels, Poesen, Van Dessel, Knapen, & De Baets, 2006; Mamo & Bubenzer, 2001b; Zhang et al., 2009). The influence of the root system in controlling soil detachment capacity depends largely on the amount of fine roots and their distribution in the top soil layer since this increases the resistance by binding and bonding soil particles, impedes water flow, promotes soil permeability, and improves soil physical properties (Li, Xu, & Zhu, 1992). Soil detachment capacity reduces exponentially with increasing plant root density (De Baets & Poesen, 2010), and both root density (RD) and diameter of most plants exhibit great temporal variation during the growing season, especially for annual plant or crop in arid and semi-arid regions, for example, the Loess Plateau of China. The temporal variations in soil detachment capacity by overland flow can certainly be associated with dynamic changes in root traits, as has been demonstrated by several studies (De Baets et al., 2006; De Baets & Poesen, 2010; Zhang et al., 2009).

Compared to grassland, soil detachment capacity by overland flow in cultivated lands is strongly influenced by tillage practices (Zhang et al., 2009). Most tillage practices, i.e. planting, ploughing, weeding, and harvesting, disturb the soil surface to form a loose erodible layer, which will influence the temporal variation in soil detachment capacity (Zhang et al., 2009). Soil loss can decrease greatly with time after tillage due to soil consolidation (Knapen, Poesen, Govers, & De Baets, 2008; Zhang et al., 2009). In the Loess Plateau, Zhang et al. (2009) found notable temporal variations in soil detachment capacity by overland flow over the growing season for each of four examined land uses. Nevertheless, the effect of root growth on soil detachment capacity was not determined due to the small range of measured root density. In addition, the measured soil detachment capacities by overland flow are closely related to the applied hydraulic conditions. There may be a discrepancy in measured soil detachment capacities due to a constant flow shear stress (11.63 Pa) being used by Zhang et al. (2009). The temporal variation in soil detachment capacity by overland flow and its influencing factors under a wide range of flow hydraulics are not fully understood yet.

In the Loess Plateau of China, soil erosion in the cultivated lands, which is considered as the principal sediment source delivered into the Yellow River (Zhang, Liu, Tang, & Zhang, 2008; Zhang et al., 2009), has long been a central concern. Investigation of the temporal variation in soil detachment capacity by overland flow in the cultivated lands under a wide range of flow hydraulics is needed to better understand the mechanism of soil erosion for soil and water conservation in this region. The objectives of this study were to investigate the temporal variation in soil detachment capacity by overland flow using undisturbed soil samples collected from fields cropped with maize (*Zea mays* L.), millet (*Setaria italica*), soybean (*Glycine max*), and potato (*Solanum tuberosum* L.), when subjected to scouring under a wider range of hydraulic conditions and to further quantify the potential influencing factors during one growing season in 2012 in the Loess Plateau.