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Soil resistance to runoff on steep croplands in Eastern China

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ABSTRACT

The knowledge of soil resistance to runoff (reflected by rill erodibility, K_r, and critical shear stress, τ_c) of steep croplands from laboratory flume experiments and their influencing factors are unclear at a larger scale. Therefore, the disturbed soil samples (representing the freshly tilled steep croplands) of 36 soil types were collected from eastern China and scoured under different flow shear stresses to investigate the spatial variations in K_r and τ_c and their influencing factors. The results showed that the soil "Argi-Udic Ferrosols" had the lowest K_r, while the soil "Aqui-Sandic Primosols" had the highest K_r. The K_r values of the 36 soil types showed a high spatial variability. The mean K_r of the northwest Loess Plateau was significantly greater than that of the other five secondary water erosion regions. Soil texture with moderate clay and sand content had the highest K_r. τ_c showed moderate spatial variability, and no obvious correlation was detected with soil types, the six secondary water erosion regions, or soil textures. K_r was significantly correlated with the measured soil physical and chemical properties. No significant correlation was found between τ_c and measured soil properties. K_r could be satisfactorily estimated by the silt content, sand content, the geometric mean particle diameter of the soil (D_g), cation exchange capacity (*CEC*) and soil organic matter (*SOM*) ($R^2 = 0.70$).

1. Introduction

China is one of the countries suffering from serious soil erosion, with a soil erosion area of 3.57 million km^2, accounting for 37.2% of its territorial area. As a result, 26,700 km^2 of arable land (>670 km^2 each year on average) has been lost in the past 50 years (Guo, 2010). A large amount of nutrients are also lost, accompanying the loss of fertile top soil, which leads to severe land degradation. In China, 34% of degraded arable land is caused by soil erosion (Guo, 2010). The annual sediment yield of China is 5 billion tons and accounts for 8.3% of the total annual sediment yield of the world (Liu et al., 2012). It is essential to control soil and water losses of croplands to maintain the national crop yield and the sustainable development of China's economy.

According to the dominant erosive agent, three primary erosion regions (water erosion, wind erosion, and freeze and thaw erosion) were identified (Fig. 1) (E et al., 2010; Tang, 2004). The area dominated by water erosion is located in eastern of China, with an area of 4.54 million km^2 (Guo, 2010). It is the center of Chinese agriculture and industry. More than 1.15 billion people live in this area. Considering the natural conditions and soil erosion characteristics, the area dominated by water erosion is further subdivided into six secondary water erosion regions (Fig. 1): the northwest Loess Plateau (III_1), northeast low mountains and hills (III_2), north mountains and hills (III_3), south mountains and hills (III_4), the Sichuan Basin and surrounding mountains and hills (III_5), and Yunnan-Guizhou Plateau (III_6). The basic information of these regions is listed in Table 1 (E et al., 2010; Tang, 2004).

Most sediment from eastern China are eroded from steep cropland (211,700 km^2). Soil erosion is serious in most of the croplands due to severe disturbances of farming systems and irrational land uses (Knapen et al., 2007a; Zhang et al., 2009). The erosion rate of steep cropland is >5000 tons km^{-2} per year in most areas of the upper and middle reaches of the Yangtze River and the Yellow River (E et al., 2010). 900 million tons of sediments are produced from the steep croplands of the middle and upper reaches of the Yangtze River each year, which accounts for 40.2% of the total sediment erosion in the entire basin (Tao, 2014). More than 500 million tons of sediments are transported into the Yellow River from Shaanxi Province each year, and 40% to 60% of these sediments originate from steep croplands. The annual sediment yield of the Hai River is 402 million tons, and a quarter of these sediments come from steep cropland (E et al., 2010). Therefore, steep cropland is the key area for soil and water conservation in eastern China. It is imperative to understand soil erosion mechanisms and the spatial variability of soil erosion on steep croplands in order to design soil and water conservation measures and to evaluate benefits.

Soil erosion can be described by the three sub-processes of soil detachment, sediment transport and deposition (Nearing et al., 1989). Soil detachment is defined as the dislodging of soil particles from the soil mass by erosive agents, providing loose, non-cohesive sediment for subsequent transport and deposition (Zhang et al., 2003). Soil

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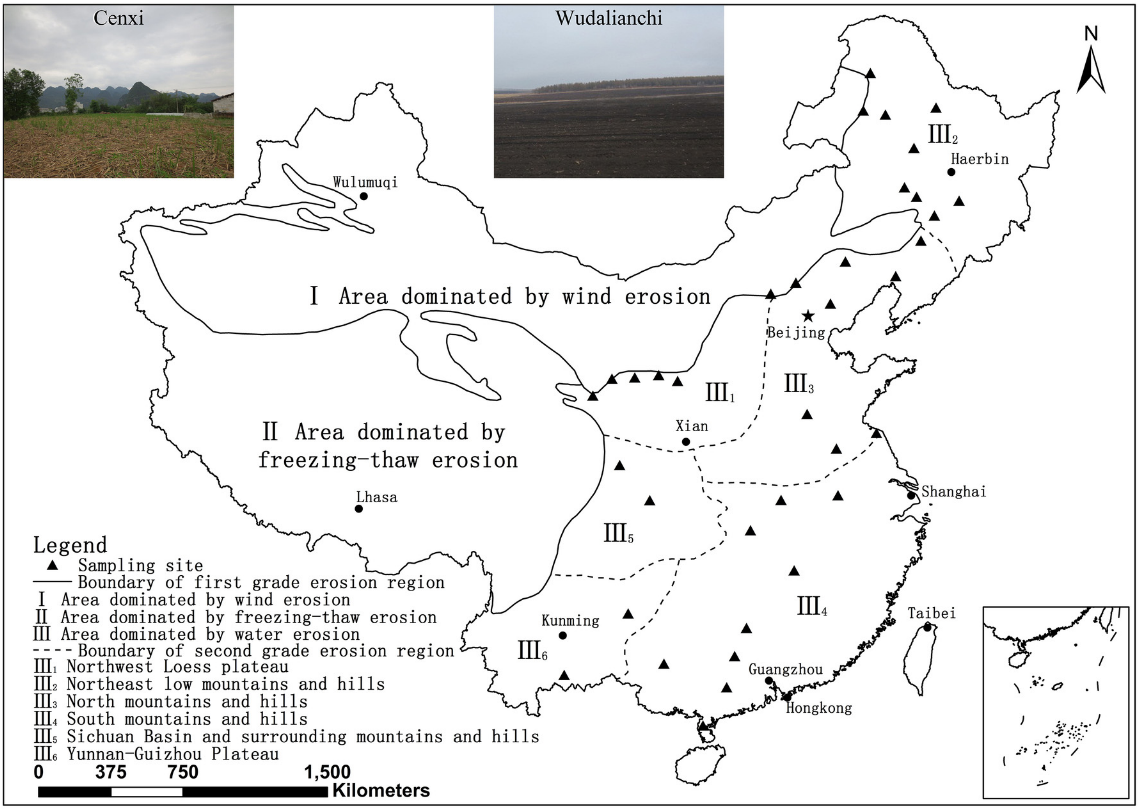

Fig. 1. Diagram showing three primary erosion regions, six secondary water erosion regions and the location of sampling sites. (Sources: E et al. (2010) and Tang (2004)).

detachment capacity (D_c) by overland flow (e.g., rill erosion) is the maximum soil detachment rate when the sediment concentration is zero (Zhang et al., 2009). In the Water Erosion Prediction Project (WEPP) model, D_c is expressed as (Nearing et al., 1989):

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

where D_c is the soil detachment capacity (kg m^{-2} s^{-1}), K_r (s m^{-1}) is the rill erodibility, τ (Pa) is the flow shear stress, and τ_c (Pa) is the critical shear stress. When the measured D_c is plotted against τ, K_r and τ_c can be estimated as the slope and the intercept on the x axis of a linear regression line (Nearing et al., 1989). Both K_r and τ_c, reflect the soil resistance to runoff and are important input parameters in process–based erosion models (Knapen et al., 2008; Wang et al., 2014).

Many studies have shown that K_r and τ_c are mainly influenced by soil physical and chemical properties as well as farming activities (Knapen et al., 2007a). Soil physical properties, including soil texture, bulk density, soil cohesion, and soil aggregate stability, greatly influence K_r and τ_c (Bennett et al., 2000; Govers et al., 1990; Léonard and Richard, 2004; Sheridan et al., 2000; Zhang et al., 2008). Soil chemical properties,

Table 1
Basic information of six secondary water erosion regions.

Secondary water erosion region	Topography	Climatic zone	Farming system	General characteristics of soil erosion
Northwest Loess Plateau	Hills Plain	Mid-temperate Warm temperate	Upland crop Wheat Wheat and upland crop	One of the world's most severe erosion regions; erosion rates are 5000–10,000 tons km^{-2} a^{-1}; the main sediment source of the Yellow river.
Northeast low mountains and hills	Plateau Mountain Hill Plain	Cold temperate Mid-temperate Warm temperate	Upland crop Wheat Rice	Moderate erosion; mainly steep cropland erosion, which composes 80% of the total erosional area and decreases the depth of black soil.
North mountains and hills	Mountain Plain Hill	North subtropics Mid-temperate Warm temperate	Wheat and upland crop Wheat Upland crop	Poor vegetation coverage; shallow soil depth; threatens the integrity of the Huai River and the Hai River.
South mountains and hills	Plain Hill Mountain	Tropical margin South subtropics Mid-temperate Mid-subtropics	Rice and wheat Rice and upland crop Rice Wheat and upland crop	The second most severe erosion region of China; the erosion rate is 3419.8 tons km^{-2} a^{-1}; severe collapsing erosion.
Sichuan Basin and surrounding mountains and hills	Mountain Basin Hill Plain	North subtropics Mid-subtropics Warm temperate	Rice and wheat Rice and upland crop Rice Wheat and upland crop	Vast area of steep cropland; steep slope cultivation; moderate erosion; one of main sediment sources of the Yangtze River.
Yunnan-Guizhou Plateau	Plateau Mountain Hill	Tropical margin Mid-subtropics Warm temperate	Rice and wheat Rice and upland crop Rice	Light to moderate erosion; severe stony desertification induced by steep slope cultivation.