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Role of soil erodibility in affecting available nitrogen and phosphorus losses under simulated rainfall

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SUMMARY

The loss of available nutrients and the effects of soil erodibility on available nutrients losses were rarely researched. Here, laboratory simulation experiments were conducted to determine the soil erodibility effects on the available nitrogen (AN) and phosphorus (AP) losses. The impacts of rainfall intensity and slope on AN and AP losses were also studied. Two contrasting agricultural soils (Burozems and Cinnamon) that occur throughout the northern erosion region of China were selected. Two rainfall intensities (60 and 120 mm h^{-1}) and two slopes (10% and 20%) were studied. Overall, greater runoff, sediment and available nutrient losses occurred from the Cinnamon soil due to its greater soil erodibility, which was approximately 2.8 times greater than that of the Burozems soil. The influence of runoff on sediment was positively linear. The absolute slope of the regression line between runoff rate and sediment yield rate was suitable as a soil erodibility indicator. Runoff-associated AN and AP losses were mainly controlled by runoff rate, and were weakly affected by soil erodibility ($p > 0.05$). However, soil erodibility significantly influenced the sediment-associated AN and AP losses ($p < 0.01$), and a positive logarithmic correlation best described their relationships. Since the runoff-associated AN and AP losses dominated the total AN and AP losses for both soils, soil erodibility also exhibited negligible influence on the total AN and AP losses ($p > 0.05$). Increasing rainfall intensity and slope generally increased the runoff, sediment, and available nutrient losses for both soils, but had no significant influences on their relationships. Our results provide a better understanding of soil and nutrient loss mechanisms.

1. Introduction

Soil erosion are among the most serious environmental concerns, and approximately 90% of the world's agricultural land suffers slight to severe erosion (Speth, 1994). Soil and water erosion reduce soil productivity and crop yield by reducing available water and removing on-site soil that is rich in nutrients (Pimentel et al., 1995; Quinton et al., 2010). In addition, nutrient losses that occur during runoff and sediment erosion result in off-site environmental effects (e.g., eutrophication) (Pimentel et al., 1995; He et al., 2003; Morgan, 2005; Zhang et al., 2011). Water-eroded land accounts for 15.6% of China's total land area (Wen, 1993). Diffuse nutrient loading from agricultural areas is considered as one of the main ecological threats in the Chinese aquatic environment (Wang et al., 2009).

Numerous studies have examined runoff, sediment and nutrient loss in the field or laboratory, as well as related influencing factors, such as rainfall intensity, slope, vegetation coverage, land use and other management practices (Flanagan et al., 2002; Benik et al., 2003; Faucette et al., 2004; Pan and Shangguan, 2006; Ramos and Martínez-Casasnovas, 2006; Zhang et al., 2011; Gilley et al., 2012; Shipitalo et al., 2013). Furthermore, several studies have reported the influence of runoff on sediment, and the influence of runoff and sediment on nutrient loss, as well as the effects of different factors (slope and land use) on these influence (Huang and Bradford, 1993; Kothyaria et al., 2004). However, previous studies have mainly focused on total nutrient (e.g., total nitrogen and total phosphorus) losses. Few studies have been conducted regarding available nutrients, which are more representative for soil fertility and are more important for plant growth. In addition, previous studies have focused on nutrients in eroded sediments (e.g., nutrient enrichment) rather than in runoff water. However,

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nutrient losses through runoff have the same environmental implications as nutrient losses through sediment (Zhang et al., 2011; Gilley et al., 2012). For example, the majority of available nutrients are dissolved in the soil solution or adsorbed on clay-humus complexes (Bormann and Likens, 1967). These nutrients can easily be carried off by runoff water through dissolution and desorption. Thus, it is important to study available nutrient loss in both runoff and eroded sediments, and the influence of runoff and sediment on available nutrient loss.

The resistance of soil to erosion is generally regarded as soil erodibility, which is an important parameter for estimating soil loss and implementing soil conservation practices (Wang et al., 2013). Soil erodibility has been qualitatively evaluated as a type of indicator and has been quantitatively evaluated using factors such as soil erodibility factor K in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) and soil erodibility coefficients in the Water Erosion Prediction Project (WEPP) (Foster and Lane, 1987). Soil erodibility should be considered as a dynamic term because it is related to intrinsic soil properties that change during storm events and due to exogenic erosional forces, which vary in space and time (Wang et al., 2013). Nevertheless, soil erodibility is generally considered as constant throughout the year for a given soil type in the most widely used soil erosion prediction models (Bouyoucos, 1935; Zhang et al., 2004). Several studies have concentrated on evaluating and calculating soil erodibility and on determining its influencing factors (e.g., soil physical properties and climatic factors) (Coote et al., 1988; Torri et al., 2002; Salvador Sanchis et al., 2007). However, relatively less information is available regarding the impacts of soil erodibility on nutrient loss. Particularly, little is known regarding the impacts of soil erodibility on available nutrient loss.

Therefore, the objective of this study was to investigate the influence of soil erodibility on available nitrogen and phosphorus losses. Available nutrient losses are accompanied by runoff and sediment, and sediment co-occurs with runoff. Hence, the influence of runoff on sediment, and the influence of both runoff and sediment on available nutrient losses would be discussed prior to the discussion about soil erodibility effects on available nutrient losses. Two typical agricultural and significantly erodible soils were selected in the northern erosion region of China, which is one of the four major erosion regions in China (Wen, 1993). A series of laboratory simulation experiments were conducted. Because rainfall intensity and slope are two critical influencing factors for soil erosion and nutrient loss, the impacts of rainfall intensity and slope were also discussed.

2. Material and methods

2.1. Soil and soil flume preparation

The two soils used in this study were the Burozem and Cinnamon soils, which were collected from field sites on the Qingdao Agricultural University Experiment Station. These soils are important agricultural soils that are typically found in sloping field soils and represent the most common soil types in the northern erosion region of China. After collecting the soil samples from their original sites, the soils were air-dried and passed through a 4.75 mm aperture square-hole sieve to remove coarse rocks and organic debris. Soil physical and chemical properties were measured by following the methods of ISSCAS (1997). The particle-size distribution was determined by using the pipette method. Soil bulk density was measured using the ring method. The saturated hydraulic conductivity (K_s) for each soil was also calculated by using the SSCBD (sand, silt, and clay percentages, bulk density) model in the Rosetta (version 1.2) (Schaap et al., 2001). Soil water content

Table 1
Mechanical composition, bulk density, saturated hydraulic conductivity (K_s), soil water content, pH, organic matter (OM), cation exchange capacity (CEC), available nitrogen (AN) and available phosphorus (AP) of two soil samples collected from the study area (mean ± standard deviation).

Soil type	Mechanical composition (%)				Bulk density (g/cm^3)	K_s (cm/day)	Soil water content (%)	pH	OM (g/kg)	CEC (cmol/g)	AN (mg/kg)	AP (mg/kg)
	>0.1 mm	0.1–0.05 mm	0.05–0.01 mm	<0.01 mm								
Burozems	45.33 ± 1.12	31.40 ± 0.76	19.94 ± 0.95	3.32 ± 0.39	1.32 ± 0.07	172.78 ± 1.32	3.7 ± 0.09	6.7 ± 0.11	8.66 ± 0.68	21.4 ± 1.21	19.90 ± 2.05	3.50 ± 0.24
Cinnamon	9.05 ± 0.63	56.97 ± 1.47	24.98 ± 1.66	8.99 ± 0.78	1.65 ± 0.11	25.43 ± 1.21	5.8 ± 0.21	6.5 ± 0.02	10.22 ± 0.82	78.2 ± 3.32	70.00 ± 2.58	8.70 ± 0.51