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Relationship between soil erodibility and modeled infiltration rate in different soils

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SUMMARY

The relationship between soil erodibility, which is hard to measure, and modeled infiltration rate were rarely researched. Here, the soil erodibility factors (K and K_e in the USLE, K_i and K_1 in the WEPP) were calculated and the infiltration rates were modeled based on the designed laboratory simulation experiments and proposed infiltration model, in order to build their relationship. The impacts of compost amendment on the soil erosion characteristics and relationship were also studied. Two contrasting agricultural soils (bare and cultivated fluvo-aquic soils) were used, and different poultry compost contents (control, low and high) were applied to both soils. The results indicated that the runoff rate, sediment yield rate and soil erodibility of the bare soil treatments were generally higher than those of the corresponding cultivated soil treatments. The application of composts generally decreased sediment yield and soil erodibility but did not always decrease runoff. The comparison of measured and modeled infiltration rates indicated that the model represented the infiltration processes well with an N–S coefficient of 0.84 for overall treatments. Significant negative logarithmic correlations have been found between final infiltration rate (FIR) and the four soil erodibility factors, and the relationship between USLE-K and FIR demonstrated the best correlation. The application of poultry composts would not influence the logarithmic relationship between FIR and soil erodibility. Our study provided a useful tool to estimate soil erodibility.

1. Introduction

Soil erosion is a significant environmental concern because it removes soil rich in nutrients and increases sedimentation in rivers (Wang et al., 2009). The rate of soil erosion by rainfall is influenced by climatic, physical, hydrological, chemical, mineralogical and biological factors, such as rainfall depth and energy, runoff depth and velocity, and the soil's susceptibility to erosion (Rodriguez-Iturbe et al., 2007). Among those factors, the susceptibility of soil to erosion, termed soil erodibility, has been qualitatively evaluated as a key indicator for estimating soil loss and implementing soil conservation practices (Wang et al., 2013). In most soil erosion models, soil erodibility has generally been considered an inherent soil property with a constant value, which is often estimated from the empirical relations between soil physical and chemical properties, such as the content of organic matter and its chemical composition (Zhang et al., 2004; Rodriguez-Iturbe et al., 2007). In the empirical Universal Soil Loss Equation (USLE), soil erodibility is estimated based on soil texture, organic matter content, structural group, and permeability class (Wischmeier and Smith, 1978). In the process-based Water Erosion Prediction Model (WEPP) (Flanagan and Nearing, 1995), the baseline interrill erodibility is calculated based on soil texture factors alone (Alberts et al., 1995). However, soil erodibility is actually a dynamic process because it is related to intrinsic soil properties that will change during storm events and to exogenic erosional forces which will vary in space and time (Wang et al., 2014). Therefore, it becomes a challenge to measure the changing values of soil erodibility in simulations of soil erosion. The accurate measurement of soil erodibility under natural rainfall conditions is both time-consuming and costly. Laboratory rainfall simulation has been used extensively as a cost-effective method, which also includes better control of the test environment to facilitate the study of individual erosion processes (Ben-Hur and Agassi, 1997).

Soil erodibility depends on the primary particle distribution, how strongly these particles are aggregated together, and whether runoff occurs during a rainfall event (Duiker et al., 2001). Under rainfall impact, a raindrop breaks soil aggregates at the surface soil layer. Simultaneously with the breakdown and dispersion of soil aggregates, small soil particles are released and a structural soil crust of low saturated hydraulic conductivity is formed at the top soil layer. The rainfall infiltrates until the application rate exceeds

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the saturated hydraulic conductivity, and the soil will eventually be unable to maintain an infiltration rate equal to the rainfall intensity; at this point, ponding occurs on the soil surface, and runoff and erosion begin (Kim et al., 1996). Connections between soil erosion and infiltration processes have been discussed in several previous studies (Agassi et al., 1994; Torri et al., 2002; Salvador Sanchis et al., 2008), with most of these focused on evaluating the factors influencing infiltration and soil erosion. Less information is available regarding the relationship between soil erodibility and infiltration rate. Ben-Hur and Agassi (1997) first recognized surface soil dispersion as a dominant controlling factor for both infiltration and soil erodibility. Yu et al. (2006) stated the relationships between the post-ponding infiltration rate and the soil erodibility of two cultivated soils in China, and explained that this relationship is highly affected by surface soil layer properties and rainfall patterns. Because infiltration rate can be more easily measured in a laboratory rainfall simulation than soil erodibility, an explicit understanding of this relationship may supply an efficient approach to predicting soil erodibility. However, the rainfall-controlled condition (i.e., given flux) for infiltration prediction limits its further application in the prediction of erodibility. Thus, switching the infiltration process from rainfall-controlled conditions to soil-controlled conditions (i.e., ponded infiltration) will help in predicting soil erodibility. In addition, controlling soil erosion is essential to managing and conserving natural resources (Hudson, 1995). Currently, many experimental studies have suggested that the use of compost applications could improve existing erosion control technologies (Demars et al., 2000; Glanville et al., 2004; Mitchell, 1997). Some of these investigators discussed the influence of organic composts on soil erodibility (Tejada et al., 2006), but the mechanisms behind the erosion control were not well-defined. Meanwhile, many studies focus on the influence of organic composts on water quality, and a few studies reported the influence of organic composts on the relationship between soil erodibility and infiltration rate.

Therefore, a series of laboratory rainfall simulations were conducted for this study. The objectives of this study include (1) to investigate the soil erosion and erodibility characteristics in natural and compost-amended soil; (2) to model the infiltration rate under the soil-controlled conditions; and (3) to determine the relationship between the modeled infiltration rate and soil erodibility.

2. Materials and methods

2.1. Soil and soil flume preparation

Bare and cultivated fluvo-aquic soils with different soil properties (especially in organic matter) were selected as two representative soils in this study and were collected from the Qingdao Agricultural University Experiment Station. Fluvo-aquic soil is one of the most important agricultural soils and accounts for 15.9% of China's total land area, which is widely distributed throughout the Huanghuaihai plain of China (ONSS, 1998). The name of fluvo-aquic soil is based on the Chinese National Standards for soil taxonomy (GBT 17296-2009), which is roughly equivalent to the Aquic Ustochrepts in the American Soil Taxonomy and the Eutyic Cambisols in the soil classification of United Nations. Meanwhile, the poultry composts were chosen because poultry manure is the most common manure in the rural area of China. Composts are defined as organic materials that have gone through a microbiological heat process and have decomposed to biologically stable, humus-rich materials (A1exander, 1996). In this paper, poultry compost rates of 20 kg m^{-3} (low compost treatment group) and 100 kg m^{-3} (high compost treatment group) were applied to the two natural soils and were mixed well for one month. The two original soils were considered as a control group. After the amendment with poultry composts, all of the soils in the control and compost treatment groups were air-dried and sieved through a 4.75 mm aperture square-hole sieve to remove coarse rocks and organic debris. Soil properties such as the particle-size distribution, bulk density, water content, pH, organic matter (OM) and cation exchange capacity (CEC) were measured using procedures outlined in the test method for the examination of soil physical and chemical properties (ISSCAS, 1997). The saturated hydraulic conductivity (K_s) was determined by using the SSCBD model in Rosetta (version 1.2) (Schaap et al., 2001). All measurements were conducted twice. The soil properties prior to the rainfall experiments are listed in Table 1.

The soil flumes were structured with metal sheets and had the following dimensions: 2.0 m length × 0.75 m width × 0.5 m height. The structure had slope-adjusting screws, allowing for control of the flume slope. The soil flumes were prepared following the method by Römkens et al. (2002) with very fine sand in the bottom 0.02–0.03 m layer of soil in the flumes (the drain beds in which the perforated drains were located) to facilitate drainage. Soils of size 0–4 mm were packed carefully in the subsequent layer of the flumes, between 0.03 and 0.15 m. Next, the preprocessed soils of the control and compost treatments groups were uniformly spread over the surface layer of the flume beds, tamped with a wooden block, and scraped to a uniform surface thickness of 0.4 m.

2.2. Rainfall experiments design

The sprinkling rainfall simulator was used to generate precipitation with varying intensities. This simulator consists of three groups of oscillating TSPT-X type nozzles, and the connections with the water supply and the pump. The design, operating principles and characteristics of our rainfall simulator were similar to the multiple-intensity rainfall simulator described by Römkens et al. (2002). In this study, there were three soil treatments for each soil (control, low- and high-compost treatments). The same rainfall experiment design was conducted for all the treatments with fixed bed slope (10°) and three successive rainfall simulation events (with intensities of 60, 90 and 120 mm h^{-1}). The duration of each

Table 1
Mechanical composition, bulk density, soil water content, pH, organic matter (OM), cation exchange area capacity (CEC) and saturated hydraulic conductivity (K_s) of two soil samples and their compost treatments.

Soil	Compost treatments	Mechanical composition (%)				Bulk density (g/cm^3)	Soil water content (%)	pH	OM (g/kg)	CEC (cmol/g)	K_s
		>0.1 mm	0.1–0.05 mm	0.05–0.01 mm	<0.01 mm						
Bare fluvo-aquic soil	Control	31.10	45.30	21.18	2.42	1.16	6.7	7.92	12.2	7.83	85.03
	Low	25.68	47.07	24.00	3.25	1.06	13.2	8.29	29.45	8.42	87.66
	High	28.96	48.53	19.11	3.40	0.92	15.9	8.76	52.52	13.25	88.90
Cultivated fluvo-aquic soil	Control	40.53	43.73	13.66	2.08	1.11	4.7	7.47	18.8	7.24	90.46
	Low	39.18	46.63	10.59	3.60	1.07	15.7	7.9	37.98	8.12	99.22
	High	50.10	34.65	12.24	3.01	0.93	16.1	8.74	55.69	12.83	103.11