Agriculture, Ecosystems and Environment 249 (2017) 226–236

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Research Paper

Effects of erosion degree and rainfall intensity on erosion processes for Ultisols derived from quaternary red clay

Xinliang Wu[a], Yujie Wei[a], Junguang Wang[a], Jinwen Xia[a], Chongfa Cai[a,*], Lanlan Wu[b], Zhiyong Fu[c], Zhiyuan Wei[a,d]

[a] Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River) of the Ministry of Agriculture, College of Resources and Environment, Huazhong Agricultural University, Wuhan, 430070, China

[b] College of Engineering, Huazhong Agricultural University, Wuhan, 430070, China

[c] Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha, Hunan, 410125, China

[d] Institute of Tropical Crops Genetic Resources, Chinese Academy of Tropical Agricultural Sciences, Danzhou, Hainan 571700, China

ARTICLE INFO

Keywords:
Land degradation
Rainfall characteristics
Field plot
Soil erodibility
Sediment selectivity

ABSTRACT

Soil erosion poses a major threat to the sustainability of soil and water resources. Soil horizons differ in their properties due to pedogenic differentiation. Currently, limited research attempts have been made to assess the impact of the removal of topsoil horizons on the subsequent erosion process. The main objective in this study was to investigate the effects of erosion degree and rainfall intensity on erosion process and sediment transport mechanism. Field plot experiments were conducted on pre-wetted bare fallow Ultisols (derived from quaternary red clay) under four erosion degrees (no (E0), moderate (E1), severe (E2), and very severe (E3)) and two rainfall intensities (60 and 120 mm h^{-1}). The erosion degrees were judged according to the outcrop of eluvium, illuvium (B1, B2) and parent material horizons. The simulated rainfall lasted one hour after runoff generation, and runoff and sediment were sampled at 3-min intervals to determine the runoff coefficient, sediment concentration, soil detachment rate and sediment effective size distribution. Runoff coefficient was negatively correlated with bulk density ($r = -0.76$, $p < 0.05$). Sediment concentration and soil detachment rate decreased with an increased erosion degree at the low rainfall intensity while they decreased in the order of E1 > E0 > E2 > E3 at the high rainfall intensity. Rainfall intensity and clay content played the negative and positive roles in the erosion process, respectively (Adj-$R^2 > 0.80$, $p < 0.01$). For E3, sediment transport was dominated by suspension/saltation (< 0.1 mm) while for the other erosion degrees it was dominated by mechanisms of both suspension/saltation and rolling (2–0.5 mm). The average sediment size was positively correlated with silt content ($r = 0.82$, $p < 0.05$). The high variation of erosion process with erosion degree was intrinsically attributed to the difference in soil horizon nature (mainly soil texture and bulk density) and also influenced by rainfall intensity to varying extent, which should be considered in future erosion prediction.

1. Introduction

Soil erosion is a main mechanism of land degradation and has posed a major threat to the sustainability of natural ecosystems (Lal, 2001; Dlamini et al., 2011). Sediment losses are generally associated with the erosion of soil organic matter, nutrients and contaminants that have direct or indirect impact on the on-site and off-site soil functions, aquatic, terrestrial and atmospheric ecosystems (Mchunu and Chaplot, 2012; Chaplot et al., 2012; Glendell and Brazier, 2014; Müller-Nedebock et al., 2016). Soil erosion by water involves the processes of detachment, transport and deposition of soil materials (Kinnell, 2000). Knowledge of the mechanism of erosion process and controlling factors will help to improve erosion management and develop reliable prediction models.

Soil erosion by water is related to a number of factors such as rainfall characteristics, soil properties and surface conditions (antecedent moisture content, roughness and slope length and steepness, vegetation cover) (Kinell, 2000; Chaplot and Le Bissonnais, 2003; Angulo-Martinez et al., 2012; Defersha and Melesse, 2012; Mahmoodabadi and Sajjadi, 2016). Dlamini et al. (2011) and Podwojewski et al. (2011) reported that sediment losses were negatively correlated with the proportion of vegetation coverage. Raindrop impact is the utmost important factor driving soil erosion, not only detaching soil materials but also enhancing sediment transport (Zhang

* Corresponding author.
E-mail addresses: wuxinlianghzau@163.com (X. Wu), weyujay@gmail.com (Y. Wei), hzaucfcai@163.com (C. Cai).

http://dx.doi.org/10.1016/j.agee.2017.08.023
Received 3 April 2017; Received in revised form 16 August 2017; Accepted 17 August 2017
0167-8809/

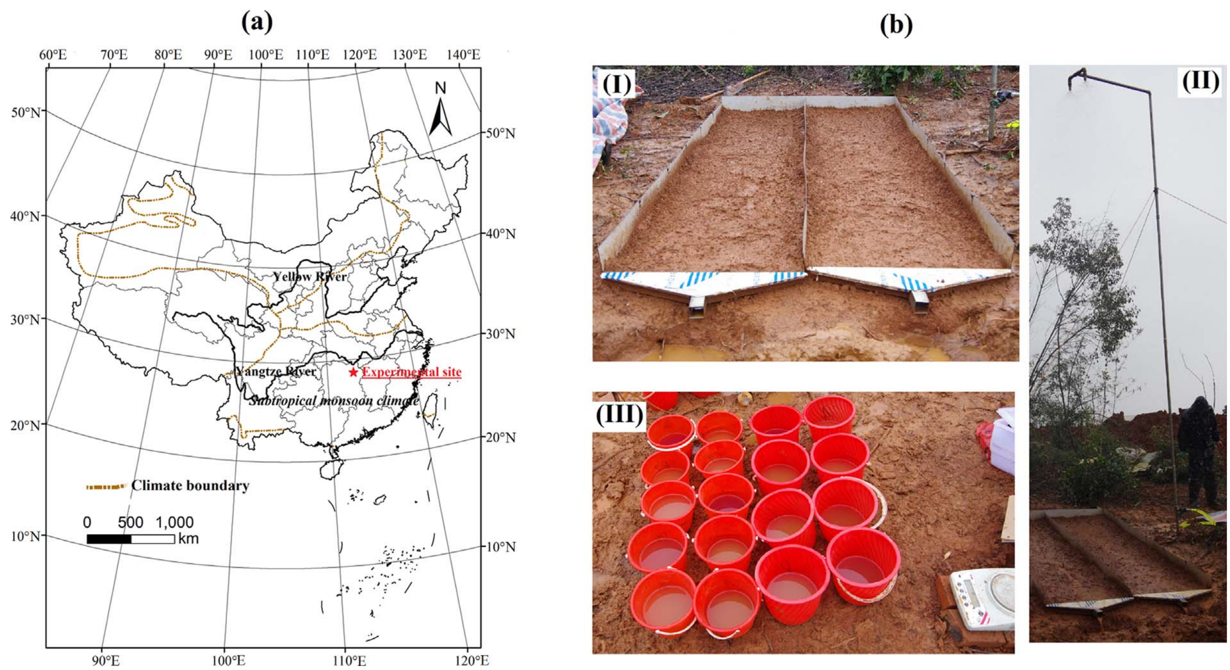

Fig. 1. Location of experimental site (a) and field experiment components (b) including field plot (I), rainfall simulator (II) and sample collector (III).

Table 1
Soil physicochemical properties in different erosion degrees (mean ± standard deviation).

ED	G_s	SOC (%)	BD (g cm^{-3})	FMC (g g^{-1})	NP (cm^3 cm^{-3})	CP (cm^3 cm^{-3})	Sand (%)	Silt (%)	Clay (%)	MWD_{FM} (mm)
E0	2.70 ± 0.00	2.59 ± 0.01	1.13 ± 0.06	0.34 ± 0.03	0.16 ± 0.03	0.43 ± 0.02	7 ± 1	42 ± 1	51 ± 0	2.80 ± 0.34
E1	2.72 ± 0.01	0.28 ± 0.01	1.31 ± 0.02	0.30 ± 0.01	0.10 ± 0.02	0.42 ± 0.01	5 ± 0	44 ± 0	52 ± 0	3.50 ± 0.39
E2	2.73 ± 0.01	0.18 ± 0.02	1.31 ± 0.02	0.30 ± 0.00	0.09 ± 0.01	0.42 ± 0.01	5 ± 0	42 ± 0	53 ± 0	2.60 ± 0.14
E3	2.74 ± 0.01	0.06 ± 0.00	1.56 ± 0.01	0.23 ± 0.01	0.05 ± 0.02	0.38 ± 0.01	6 ± 0	39 ± 3	55 ± 3	4.43 ± 0.51

Note: ED, erosion degree; E0, E1, E2 and E3 denote no, moderate, severe and very severe erosion degrees, respectively; G_s, particle density; SOC, soil organic carbon; FMC, field moisture content; NP and CP, non-capillary and capillary porosity; Sand, 2–0.05 mm; Silt, 0.05–0.002 mm; Clay, < 0.002 mm; MWD_{FM}, mean weight diameter of aggregates at the field moisture content.

and Wang et al., 2017). Soil properties and rainfall characteristics often have an interactive effect on erosion processes through altering surface conditions such as crust that affect both water infiltration and soil detachability (Bradford and Huang, 2000; Le Bissonnais et al., 2005; Carmi and Berliner, 2008; Wang et al., 2013). The actual effect of rainfall intensity on sediment concentration and sediment yield varied with soil types (Defersha and Melesse, 2012). Martínez-Mena et al. (2002) reported that the predominant erosion processes were dependent on and independent of rainfall intensity in the calcareous colluvial soil and marl soil, respectively. Maïga-Yaleu et al. (2013) investigated the various effects of crust types on soil erosion and found that structural crust on clayey soils and perennial desiccation crust on sandy soils generated the least and largest amount of sediment losses, respectively. During the erosion process, sediment delivery is set to the lesser of the sediment transport capacity and the amount of detached particles available for transport (Kinnell, 2005).

In addition to runoff and soil loss, sediment size distribution and its dynamic variation would facilitate the understanding of erosion and sedimentation processes (Kinnell, 2006; Asadi et al., 2007, 2011; Shi et al., 2012; Defersha and Melesse, 2012). Many previous studies investigated sediment transport mechanisms (suspension, saltation and rolling) by comparing the sediment size distribution with the original soils (Asadi et al., 2007, 2011; Shi et al., 2012; Wang et al., 2014). These detached materials move downstream in various ways, which depend on their size, density, shape and flow hydraulic characteristics (Kinnell, 2006). Coarse material was transported as bed load while the finer material remained suspended (Kinnell, 2006). Compared to the ultimate particle size, the effective particle size of sediments probably better indicate how the soil was detached and transported by raindrop and runoff especially for soils in strong aggregation such as clay Ferrosol and Vertosol (Martínez-Mena et al., 2002; Asadi et al., 2007; Shi et al., 2012).

For most soil types, soil horizons differ in their properties due to pedogenic differentiation, such as aggregate stability, porosity, and organic matter (Turski et al., 1992; Rejman et al., 1998; Wu et al., 2016). Wu et al. (2016) have recently reported that their water stability of air-dried aggregates generally decreased while mechanical strength increased with profile depth for highly weathered soils. In many water erosion regions, soil thickness decreased to different degree after the removal of surface soils under the impact of water erosion or human activity, even with the parent material horizon exposed somewhere (Zhang et al., 2004; Dlamini et al., 2011; Podwojewski et al., 2011). Rejman et al. (1998) reported large differences in soil loss in dependence on erosion degree for loess soils. Podwojewski et al. (2011) reported that the removal of the A horizon increased sediment concentration and soil loss by a factor of 4. In addition to these studies, to our knowledge, limited attempts have been made to systematically assess the impact of soil erosion removal on the subsequent erosion process (including sediment size characteristics), let alone at the field condition.

In this context, the main objective of this study was to determine the effect of erosion degree and rainfall intensity on erosion processes and sediment transport mechanisms, with a specific focus on (i) the temporal variation of runoff, sediment concentration and detachment rate