Catena 123 (2014) 153–162

Contents lists available at ScienceDirect

Catena

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

Particle size and shape variation of Ultisol aggregates affected by abrasion under different transport distances in overland flow

Jun-guang Wang, Zhao-xia Li, Chong-fa Cai *, Ren-ming Ma

Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River) of the Ministry of Agriculture, Soil and Water Conservation Research Centre, Huazhong Agricultural University, Wuhan 430070, People's Republic of China

ARTICLE INFO

Article history:
Received 1 December 2013
Received in revised form 27 July 2014
Accepted 31 July 2014
Available online 23 August 2014

Keywords:
Aggregate stability
Particle size and shape variation
Transport distance
Overland flow

ABSTRACT

Particle size variation or distribution is a recognized factor influencing crust characteristics, water infiltration and sediment transport during slope erosion. Limited studies have been conducted about particle size and shape variation resulting from the abrasion of soil aggregate in overland flow. This experiment was based on aggregate abrasion in a 3.8 m long flume with a fixed bed, and the particle size and shape variations were studied using dry sieving method and a Laser particle size and shape analyzer. Results indicated that the high abrasion rate of large particles (particles larger than 5 mm) caused the mass percentage of particles in intermediate size ranges (2 mm–1 mm, 1 mm–0.5 mm and 0.5 mm–0.25 mm) increased with transport distance. The D_{50} values of Average Feret Diameter of smaller abraded aggregates (0.0385 mm–0.25 mm) increased first and then decreased, and their shape became more regular and rounder with the transport distance. There were significant negative correlations between *RMI* (relative mechanical breakdown index) of initial aggregates with *MWD* (Mean weight diameter) for particles larger than 0.25 mm, and with Cir_m (median value of Circularity Factor) for particles smaller than 0.25 mm in all the five transport distances ($p < 0.05$). These indicated that the initial aggregates had low susceptibility to mechanical breakdown, resulting in weak abrasion of particles larger than 0.25 mm and regular shape of particles smaller than 0.25 mm under certain transport distance in overland flow. A multiple regression equation was established, relating Cir_m to *RMI* and transport distance (x) for estimating the particle shape of smaller abraded aggregates in overland flow. The information of the analysis of particle size and shape variation can be useful for the development of soil process-based erosion models.

1. Introduction

Soil water erosion involves detachment, transport and deposition of soil materials due to erosive forces of raindrops and runoff, and these processes are commonly divided into interrill and rill components depending on the source of eroded sediment (Bradford and Huang, 1996; Meyer and Wischmeier, 1969; Rose, 1985). Stable soil aggregates can reduce detachment by raindrop impact and transport by runoff, and can also reduce the possibility of forming surface crusts and seals (Martínez-Mena et al., 1999). Therefore, they are important in protecting soil against erosion (Barthès and Roose, 2002; Kawamoto et al., 2007; Valmis et al., 2005). Aggregate stability is often considered as an appropriate factor to assess soil erodibility or soil degradation (Barthès and Roose, 2002; Cammeraat and Imeson, 1998; Fox and Le Bissonnais, 1998). Soil susceptibility to breakdown into microaggregates, finer and more transportable particles is of major importance in erosion processes (Farres, 1987; Leguédois and Le Bissonnais, 2004). It is generally accepted that soil aggregate breakdown, by producing smaller particles, may affect sediment transport capacity and the intensity of soil erosion.

Interrill sediments are aggregates and primary particles collected with runoff, and they are detached by splash and then transported by overland flow. The particle-size distribution of eroded sediment can provide basic understanding regarding erosion processes (Meyer et al., 1992; Mitchell et al., 1983; Proffitt and Rose, 1991; Wan and El-Swaify, 1998). Leguédois and Le Bissonnais (2004) examined the relationship between aggregate stability and soil erodibility through aggregate size distribution and investigated the size selectivity on interrill erosion processes, i.e. breakdown, detachment by splash and transport by overland flow. Several studies have been documented for aggregate breakdown by splash (Legout et al., 2005; Wuddivira et al., 2009) and the effect of different aggregate sizes on infiltration and erosion characteristics under simulated rainfall (Abu-Hamdeh et al., 2006; Lado et al., 2004; Warrington et al., 2009). A number of studies tried to characterize eroded sediments in terms of their effective size distribution consisting of both primary particles (sand, silt, and clay) and soil aggregates (Martinez-Mena et al., 2002; Wang et al., 2014). Some studies reported that sediments from interrill erosion were enriched in sand at the expense of the silt and clay size fractions (Young and Onstad, 1978).

---

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, People's Republic of China. Tel.: +86 27 87288249.
E-mail addresses: junyong518@163.com (J. Wang), zxli@mail.hzau.edu.cn (Z. Li), cfcaihzau@163.com, cfcai@mail.hzau.edu.cn (C. Cai), marenming521@163.com (R. Ma).

http://dx.doi.org/10.1016/j.catena.2014.07.020
0341-8162/

Table 1
Location of sampling sites and description of Ultisols.

Sample designation	Parent material	Sampling location	Situation	Altitude (m)	Slope	Orientation	Vegetative cover, land use
SX1	Shale	Xianning[a]	N30°00′33.0″E114°19′36.3″	38	13–18%	West	Tea garden
SX2	Shale	Xianning	N30°01′22.8″E114°20′32.6″	41	17–20%	East	Prunus × cistenena, upland
SX3	Shale	Xianning	N30°00′59.4″E114°22′27.9″	52	15–18%	Southwest	Peanut, cropland
SX4	Shale	Xianning	N30°01′04.0″E114°22′27.9″	28	10–15%	East	Corn, cropland
QX1	Quaternary red clay	Xianning	N30°00′26.3″E114°21′52.1″	53	18–20%	West	Tea garden
QX2	Quaternary red clay	Xianning	N30°01′19.8″E114°21′14.6″	40	10–14%	North	Corn, cropland
QX3	Quaternary red clay	Xianning	N30°01′16.7″E114°20′55.4″	41	18–20%	West	Prunus × cistenena, upland
QX4	Quaternary red clay	Xianning	N29°59′45.3″E114°24′40.6″	48	15–18%	North	Sesame, cropland
QJ1	Quaternary red clay	Jinxian[b]	N28°21′30.2″E116°10′10.8″	33	17–20%	West	Tea garden
QJ2	Quaternary red clay	Jinxian	N28°19′56.7″E116°10′43.3″	35	14–18%	West	Cedar, upland
QJ3	Quaternary red clay	Jinxian	N28°21′31.8″E116°09′37.3″	31	20–25%	South	Weed, wild land
QJ4	Quaternary red clay	Jinxian	N28°21′21.4″E116°09′33.1″	28	10–14%	North	Sesame, cropland

[a] Xianning City.
[b] Jinxian City.

In other studies it was observed that clay, and not sand, was enriched in the eroded sediment (Alberts et al., 1983; Shi et al., 2013; Warrington et al., 2009).

In addition to the attention on the sediment selective entrainment and transport during short distances in interrill simulations, it is also important to quantify sediment transport capacity and particle size distribution in overland or rill flow. The relationship between sediment transport capacity with several hydraulic parameters in overland flows (such as, flow regime, hydraulic friction, flow discharge, shear stress, and stream power) was analyzed (Abrahams et al., 2001; Foster and Meyer, 1972; Govers, 1992; Nearing et al., 1999; Prosser and Rustomji, 2000; Prosser et al., 1995; Zhang et al., 2009). Among those studies, Farenhorst and Bryan (1995) investigated the particle selection and size distribution of transported sediment in different overland flows, and the results indicated that both transport and entrapment selectivity were strongly related to the ability of flow to transport the full range of grains present, as well as to the relationship of the bed roughness to the particles transported. However, a few reports focused on only the competence of overland flow to transport coarse sediments, such as aggregates, and did not consider the aggregate abrasion during transport processes. Abrasion is often used to explain the process of a pebble in nature river, and it is due to the friction and collisions that occur between pebbles and between one pebble and the bed, leading to the size reduction of a pebble (Le Bouteiller et al., 2011). Kuenen's abrasion classification distinguishes between seven wearing mechanisms including chipping, crushing, grinding or splitting (Kuenen, 1956). In this study, abrasion is one of the ways that the aggregate can be destroyed in overland flow. It mainly reflects the process that the aggregate is subjected to chip and grind and it does not split rapidly (Wang et al., 2012). At present, the abrasion degree and abrasion regularities of the aggregate have been obtained and interpreted in the literature of Wang et al. (2012, 2013). In order to effectively estimate the slope erosion process, it is essential to analyze the different particle size and shape variations resulting from aggregate abrasion for different transport distances in overland flow.

Ultisols (local name: red soils) cover approximately 1.14 million km^2 in south-eastern China. Undulating topography, poor soil properties, improper land use and soil management have caused severe soil erosion in this region (Zhang et al., 2004; Zhao et al., 2000). Because of the severe soil erosion, the rills and gullies caused by washing of abundant rainfalls are obvious on the surface of the soil in this area. Moreover, the presence of abundant water-stable micro-aggregates, the effect of aggregate stability on soil erosion in Ultisols is obvious and vastly differs from soils found in the temperate zone of China (Yan et al., 2008). The objectives of this work are thus: (1) to analyze the size distribution of aggregates of size larger than 0.25 mm and its variation with transport distance in overland flow; (2) to determine the variation in size and shape of smaller abraded aggregates (0.0385 mm–0.25 mm) under different transport distances in overland flow; (3) to obtain the quantitative effects of initial aggregate relative mechanical breakdown index on the particle shape factor of smaller abraded aggregates

2. Materials and methods

2.1. Soils

Two soils from different parent materials, Quaternary red clay and Shale, were collected from Xianning City in Hubei Province and Jinxian City in Jiangxi Province, China. Both sites (N28–30°and E114–116°) are in the subtropical zone with an annual rainfall of 1572 mm and 1587 mm and annual average temperatures of 16.8 °C and 17.5 °C, respectively. Elevation of these areas is 28–53 m above sea level, and the landscapes of these two areas are hills with different degrees of erosion. Within the samples, eight samples were from Xianning City, and four samples were from Jinxian City. All of the samples were geographically representative for the soils in Hubei and Jianxi Province and they were

Table 2
Selected physical and chemical properties of the tested soils.

Soils	pH (H_2O)	SOM (g kg^{-1})	CEC (cmol kg^{-1})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Texture
SX1	4.43 ± 0.16	17.26 ± 0.24	13.95 ± 1.92	244 ± 11	398 ± 64	358 ± 53	Clay loam
SX2	4.80 ± 0.32	16.67 ± 0.78	16.28 ± 1.06	126 ± 15	633 ± 27	241 ± 14	Silt loam
SX3	4.52 ± 0.25	16.35 ± 0.41	14.35 ± 1.65	235 ± 8	439 ± 14	326 ± 12	Clay loam
SX4	4.56 ± 0.28	18.13 ± 0.56	15.63 ± 1.54	218 ± 11	399 ± 21	383 ± 22	Clay loam
QX1	4.39 ± 0.21	17.55 ± 0.35	15.18 ± 1.57	189 ± 7	313 ± 11	498 ± 16	Clay
QX2	4.28 ± 0.14	15.34 ± 0.29	15.63 ± 1.79	67 ± 12	471 ± 14	462 ± 21	Silty clay
QX3	4.51 ± 0.14	21.16 ± 0.56	19.38 ± 1.57	86 ± 13	375 ± 26	539 ± 34	Clay
QX4	4.64 ± 0.31	16.59 ± 0.79	14.05 ± 1.84	181 ± 13	314 ± 34	505 ± 10	Clay
QJ1	5.05 ± 0.16	13.11 ± 0.68	16.27 ± 2.31	193 ± 11	352 ± 12	455 ± 4	Clay
QJ2	4.31 ± 0.04	25.35 ± 0.71	17.40 ± 1.21	153 ± 4	416 ± 3	431 ± 6	Silty clay
QJ3	5.14 ± 0.04	22.74 ± 0.90	16.65 ± 1.39	92 ± 29	399 ± 12	509 ± 34	Silty clay
QJ4	4.27 ± 0.03	12.05 ± 0.28	15.75 ± 0.41	289 ± 13	297 ± 12	414 ± 24	Clay

Values are means ± stand error ($n = 5$); SOM: Soil organic matter; CEC: Cation exchange capacity; sand (2–0.05 mm), silt (0.05–0.002 mm), clay (<0.002 mm).