Soil & Tillage Research 178 (2018) 150–158

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Quantifying contributions of slaking and mechanical breakdown of soil aggregates to splash erosion for different soils from the Loess plateau of China

Hai Xiao[a,c], Gang Liu[a,b,*], Qiong Zhang[a], Zheng Fenli[a,b], Xunchang Zhang[d], Puling Liu[a,b], Jiaqiong Zhang[a,b], Feinan Hu[a,b], Mohamed A. M. Abd Elbasit[e]

[a] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling 712100, People's Republic of China*
[b] *Institute of Soil and Water Conservation of Chinese Academy of Sciences and Ministry of Water Resources, Yangling 712100, People's Republic of China*
[c] *Key Laboratory of Geological Hazards on Three Gorges Reservoir Area (China Three Gorges University), Ministry of Education, Yichang 443002, People's Republic of China*
[d] *USDA-ARS, Grazinglands Research Lab., 7207 W. Cheyenne St., El Reno, OK 73036, USA*
[e] *Agricultural Research Council, Institute for Soil, Climate & Water, Private Bag X79, Pretoria 0001, South Africa*

ARTICLE INFO

Keywords:
Aggregate disintegration
Slaking
Mechanical breakdown
Rainfall kinetic energy
Soil texture

ABSTRACT

The information of aggregate disintegration mechanisms during splash erosion is scant. This study was conducted to quantify contributions of the mechanisms of aggregate disintegration to splash erosion. Six soils with five soil textures were used. Soil aggregate stability was determined by the Le Bissonnais (LB) method. Deionized water was used to simulate the combined effect of slaking and mechanical disaggregation, while ethanol was used to estimate the sole contribution of the mechanical breakdown. Simulated rainfall with intensity of $60\,\mathrm{mm\,h^{-1}}$ was applied at five fall heights (0.5 m, 1 m, 1.5 m, 2 m and 2.5 m) to achieve different levels of rainfall kinetic energy. The results indicated that slaking caused the most severe aggregate breakdown, and followed by mechanical breakdown, while chemical dispersion in slow wetting with deionized water was the weakest breakdown mechanism. The splash erosion rates due to the effects of slaking and mechanical breakdown increased with an increase in rainfall kinetic energy. The contributions of the slaking (mechanical breakdown) to splash erosion decreased (increased) as rainfall kinetic energy increased. The contribution of mechanical breakdown had a power function relation with rainfall kinetic energy, and had the most significant correlation with *RSI* (relative slaking index)/*RMI* (relative mechanical breakdown index). A power and a linear function could be used to describe the relationships between the contributions of mechanical breakdown with rainfall kinetic energy and *RSI*/*RMI*, respectively, which could be used to estimate the contribution of mechanical breakdown. The results of this research would be helpful to improving the soil erosion prediction models.

1. Introduction

Slaking (caused by the compression of air entrapped inside aggregates during wetting), differential swelling of clays, mechanical dispersion due to the kinetic energy of raindrops and physicochemical dispersion are considered as four main mechanisms for soil aggregates disintegration (Le Bissonnais, 1996). Aggregate breakdown is of significant importance in the soil detachment for which it provides fine particles that are splashable by raindrops (Wuddivira et al., 2009) and transportable by raindrop-impacted sheet flow. Auerswald (1995) concluded that air entrapment by rapid wetting was the main cause of aggregate disintegration, while swelling and clay dispersion had minor or no effect on aggregate disintegration. It was demonstrated that swelling and clay dispersion had minor or no effect on aggregate disintegration by comparing between different moisture pretreatments and liquids (Almajmaie et al., 2017). Loch (1994) demonstrated that aggregate disintegration depended on the wetting rate (slaking) at which the initially dry aggregates are wetted, and was an energetically more important process than the impact of raindrops. Fajardo et al. (2016) showed that slaking occurred mainly during the initial few minutes under fast wetting condition by using an image recognition algorithm method. Han et al. (2016) confirmed the importance of slaking on soil disaggregation. Mechanical breakdown due to raindrop impact is another important soil aggregate breakdown mechanism

---

* Corresponding author at: No. 26, Xinong Road, Yangling, Shaanxi Province, 712100, PR China.
E-mail address: gliu@foxmail.com (G. Liu).

https://doi.org/10.1016/j.still.2017.12.026
Received 4 September 2017; Received in revised form 30 December 2017; Accepted 30 December 2017

Table 1
Basic physical and chemical property of experimental soils.

Soil	Sampling location	Clay/%	Slit/%	Sand/%	Soil organic matter/ g kg^{-1}	pH value (1:2.5)	Air dried soil moisture content/%	Water drop penetration time/s	Free-form Fe/ g/kg	Amorphous Fe/g/kg	Free-form Al/ g/kg	Amorphous Al/g/kg
Loam clay soil	Yangling	26.1	40.0	33.9	6.0	8.4	2.6	0.20	7.96	0.56	3.61	0.60
Clay loam soil	Changwu	20.9	33.1	46.1	10.1	8.2	3.3	0.24	5.98	0.41	1.50	0.61
Sandy loam soil 1	Ansai	10.6	18.9	70.5	4.1	8.8	1.1	0.19	4.94	0.33	2.37	0.15
Sandy loam soil 2	Jingbian	11.5	21.4	67.1	4.8	8.8	1.0	0.27	4.94	0.30	4.80	0.38
Silty clay loam	Wugong	16.2	48.2	35.6	20.9	8.6	2.9	0.64	6.95	0.53	2.97	0.68
Loamy sand	Shenmu	6.3	6.8	86.9	2.4	8.7	1.0	0.28	4.76	0.14	0.74	0.48

during water erosion. Zhou et al. (2013) highlighted the significant importance of mechanical breakdown on aggregates during water erosion by observing the process of soil aggregate breakdown for different levels of rainfall kinetic energy. The raindrop impact is the major mechanism responsible for aggregate breakdown in the absence of slaking when soil moisture is near field capacity (Almajmaie et al., 2017). Thus, the main mechanisms of soil aggregate breakdown during water erosion processes are both slaking by fast wetting and mechanical breakdown due to raindrop impact (Shi et al., 2012; Vaezi et al., 2017). However, the information on assessing the rates of contributions of slaking and mechanical breakdown to water erosion is scant. Therefore, a systematic approach to determine the contribution rates of slaking and mechanical breakdown to water erosion during rainfall simulations is desirable.

Soil aggregation or disaggregation plays an important role in many soil functions (De Gryze et al., 2005; Deviren Saygm et al., 2012). Many researchers have reached the consensus that the indicator of structural stability of soil aggregates (Six et al., 2000), referred as aggregate stability, is in close relation to soil erosion (Mbagwu and Auerswald, 1999; Valmis et al., 2005; Shi et al., 2010; Xiao et al., 2017a). The clay, organic matter and Fe/Al oxides act as cementing agents that promote the formation of aggregates and increase aggregate stability (Puget et al., 1995; Le Bissonnais & Arrouays, 1997; Barthès et al. 2008; An et al., 2013).

The splash erosion due to raindrop impact increases with the breakdown of aggregates (Ma et al., 2014). The stability of topsoil aggregate is considered as a good indicator for both interrill (Barthès and Roose, 2002; Cantón et al., 2009; Shi et al., 2010) and rill erodibility (Wang et al., 2012). In addition, several researchers tried to use the aggregate stability, e.g. percolation stability (*PS*, an index of soil aggregate stability based on the amount of water percolated through a column of dry soil aggregates) (Mbagwu and Auerswald, 1999), instability index (β, an index of soil aggregate stability based on the mass of air-dry aggregates retained on the sieve after pre-soaked for 3 min immersion in water and 4 min oscillation) (Valmis et al.,2005; Dimoyiannis et al., 2006), for describing interrill erosion. The indexes of *PS* and β mainly reflect the fast wetting effect; however, the mechanisms primarily responsible for aggregate breakdown during water erosion processes include both slaking by fast wetting and mechanical breakdown due to raindrop impact (Shi et al., 2012). The aggregate stability index (A_s), which reflects the slaking by fast wetting and mechanical breakdown due to raindrop impact effects, was applied to replace interrill erodibility K_i (Yan et al., 2008; Shi et al., 2010) and rill erodibility factor K_r (Wang et al., 2012) in the erosion equation of the Water Erosion Prediction Project (WEPP) model. The index A_s is calculated by: $A_s = RSI \times RMI$, here *RSI* and *RMI* are relative slaking index and relative mechanical breakdown index, reflecting the susceptibility to slaking and mechanical breakdown, respectively.

Therefore, this study was conducted to quantify the contribution of the mechanisms of aggregate disintegration to splash erosion. The purposes of this study were (i) to analyze the factors affecting the contributions of slaking and mechanical breakdown to splash erosion; and (ii) to establish and verify the prediction equations for partitioning slaking and mechanical breakdown.

2. Materials and methods

2.1. Soils

Six soils with five soil textures (International System) were collected from Yangling (34°17′56″ N, 108°03′27″ E, loam clay soil), Changwu (35°13′57″ N, 107°41′20″ E, clay loam soil), Ansai (36°55′22″ N, 108°51′28″ E, sandy loam soil 1), Jingbian (37°22′55″ N, 108°49′55″ E, sandy loam soil 2), Wugong (34°25′27″ N, 108°04′22″ E, silty clay loam) and Shenmu (38°47′37″ N, 110°22′03″ E, loamy sand) in Shaanxi province, China, respectively. Soil samples collected from the