Response of soil aggregate disintegration to the different content of organic carbon and its fractions during splash erosion

Abstract

Aggregate disintegration is a critical process in soil splash erosion. However, the effect of soil organic carbon (SOC) and its fractions on soil aggregates disintegration is still not clear. In this study, five soils with similar physical and chemical properties and different contents of SOC have been used. The effects of slaking and mechanical striking on splash erosion were distinguished by using deionized water and 95% ethanol as raindrops. The simulated rainfall experiments were carried out in four heights (0.5, 1.0, 1.5, and 2.0 m). The result indicated that the soil aggregate stability increased with the increases of SOC and light fraction organic carbon (LFOC). The relative slaking and the mechanical striking index increased with the decreases of SOC and LFOC. The reduction of macroaggregates in eroded soil gradually decreased with the increase of SOC and LFOC, especially in alcohol test. The amount of macroaggregates (>0.25mm) in deionized water tests were significantly less than that in alcohol tests under the same rainfall heights. The contribution of slaking to splash erosion increased with the decrease of heavy fractions organic carbon (HFOC). The contribution of mechanical striking was dominant when the rainfall kinetic energy increased to a range of threshold between 9 J m^{-2} mm^{-1} and 12 m^{-2} mm^{-1}. This study could provide the scientific basis for deeply understanding the mechanism of soil aggregates disintegration and splash erosion.

1. Introduction

Splash erosion is an initial stage and an important component of interrill erosion (Kinnell, 2005; Van Dijk, Meesters, & Bruijnzeel, 2002). The aggregate fragmentation caused by raindrops striking is the first critical process in splash erosion (Legout, Leguedois, Le Bissonnais, & Lssa, 2005; Shainberg, Levy, Rengasamy, & Frenkel, 1992). Many studies have showed that raindrops striking can damage the soil structure, disperse and transport soil particles, thereby reducing soil permeability. The amount of soil particles splashed increases with the speed at which the raindrop hits the ground (Moss & Green, 1987). Fu et al. (2017) found that there are significant exponential relations between the distance of splash and the size of raindrops. Xiao et al. (2017) reported that the contribution of slaking decreasing with the increased of the rainfall kinetic energy in splash, and that the contribution of mechanical striking was opposite. It was also found that the soil texture plays vital role in soil aggregates disintegration during splash erosion when the soil organic carbon (SOC) was low (Xiao et al., 2018).

Soil aggregate stability is a crucial physical indicator that determine disintegration resistance in soil erosion process, it determines the resistance of the soil to erosion (Barthes & Roose, 2002; Bronick & Lal, 2005; Nichols & Toro, 2011). The SOC plays an important role in formation of aggregates (Reeves, 1997; Smith & Petersen, 2000; Tisdall & Oades, 1982). Furthermore, the physical protection of aggregates is one of the main stabilizing mechanisms of SOC (Feller & Beare, 1997; Li & Pang, 2014; Tisdall & Oades, 1982). Emerson (1967) found that 90% of SOC in the topsoil was in aggregates. Six et al. (1998; 2004) reported that the SOC is one of the most important cementing materials in aggregates. Tisdall and Oades (1982) proposed the soil aggregate theoretical model, which states that microaggregate is an important precondition to form macroaggregate.

In order to distinguish the influence of SOC on the formation of aggregates, some researchers used physical or chemical methods to classify SOC into different components (Barrios, Buresh, & Sprent, 1996; Dhillon & Van Rees, 2017; Guan et al, 2018; Six, Paustian, Elliott, & Combrink, 2000; Xiang, Zhang, & Wen, 2015).

Density fractionation of SOC is a common way to separate the SOC into light fraction organic carbon (LFOC) and heavy fraction organic carbon (HFOC) (Christensen, 1992; Turchenek & Oades, 1979; Wagai, 2009). The LFOC was labile fractions that represent an intermediate organic carbon pool between humified organic matter and undecomposed residues (Janzen, Campbell, Brandt, Lafond, & Townley Smith, 1992). The HFOC was stable that has lower carbon concentrations and slow decomposition rate and transformation rate (Golchin, Clarke, Oades, & Skjemstad, 1995a; Golchin & Oades, 1995b; Hassink, 1995; John, Yamashita, Ludwig, & Flessa, 2005). Oades (1984) and Elliott (1986) found that the roots and the fungal hyphae in LFOC can promote the formation of aggregates directly. These studies focused on the formation process of aggregates or the influences of different components of organic carbon on the particle size of aggregates (Guan et al., 2018; Holeplass, Singh, & Lal, 2004; Xiang et al., 2015). However, the role of SOC and its fractions in inhibiting the destruction of aggregates during splash erosion is still not clear.

The purposes of this study were (i) to explore the influence of SOC and its fractions on the disintegration of aggregates; (ii) to quantify the effects of SOC on contribution of slaking and mechanical striking to splash erosion.

2. Materials and methods

2.1 Study area and sampling

Five soils were collected from Fuxian (36°03′~36°04′N, 109°08′~109°09′E) in Shaanxi province, China. The soils with distinct SOC contents, due to different years after conversion from cropland to forestry, were selected. The sampling areas belong to hilly and gully regions of the Loess Plateau and the main soil type is loessial soil. The average annual temperature and precipitation in this area are 9°C and 576 mm, respectively. The main types of land use were forest. The vegetation was mainly

Ulmus pumila, *Betula platyphlla*, *Prunus*, *Populus davidiana* and so on.

Soil samples were collected from the uppermost 20 cm layer, air-dried and sieved through a 5 mm sieve to remove roots and gravels. The basic physical-chemical properties of the soils in the experiment are showed in Table 1.

2.2 Experimental design

The rainfall device is composed of three parts, including rainfall liquid supply, raindrop generation and supporting frame (Figure 1). The raindrop generation part was a cylinder with diameter of 30 cm which is made from smooth steel. Thirty-nine rainfall needles with a diameter of 0.6 mm were evenly distributed on the bottom of the cylinder. The fall height was controlled by adjusting the height of the supporting frame. Splash pan is an inverted cone device with an outer ring (30 cm diameter on top, 10 cm diameter on bottom, and 30 cm in height) and an inner ring (10 cm diameter and 10 cm in height) in the middle. Some small holes were drilled on the bottom of inner ring for drainage. The outer ring and the inner ring were connected to a smooth slope. An outlet was installed at the end of slope for water and sediment collection. The detailed description of rainfall device can be found in Xiao et al. (2017, 2018).

Before packing soil in the inner ring, the ring bottom was filled with some gravel with diameters of 1-2 cm to ensure free drainage. Then a filter paper was covered over the gravel and air-dried soil was packed over the paper. The packed soil was about 1.5 cm thick with bulk density of 1.20 g cm^{-3} and initial soil water content of 5%. The duration of simulated rainfall was 10 mins with an intensity of 60 mm h^{-1}. The kinetic energy was simulated at four different rainfall heights, 0.5 m, 1.0 m, 1.5 m and 2.0 m. Each treatment replicated twice. The splashed soil sticking on the wall of outer ring and slope was washed out with an injector, and then collected at the outlet. The collected sediment was dried and weighted. After test, the remained topsoil of 0.5 cm thick in the splash pan was collected to measure the water stable aggregates after air-dried.

Non-uniform swelling of soil minerals after wetting has limited damage to aggregates in rainfall conditions (Almajmaie, Hardie, Acuna, & Birch, 2017; Le Bissonnais, 1996). At the same time, the loessal parent material of the test soils was the least swelling mineral. Therefore, the destruction of soil aggregates by non-uniform swelling after soil mineral wetting was neglected in short duration of this study. The aggregates disintegration was mainly caused by slaking and mechanical striking (Xiao et al., 2017; 2018). The aggregates disintegration by 95% ethanol was resulted mainly from the mechanical striking because of the limited slaking effects of ethanol. Two raindrop materials (deionized water and ethanol), were used to distinguish the slaking and mechanical striking.

2.3 Measurement

Soil particle size distribution, pH value, and soil organic carbon were analyzed by a pipette method (Liu, 1996), the Rex Electric Chemical PHS-3E precision acidity meter (Shanghai Precision Scientific Instrument Co., Ltd, China) and the potassium dichromate oxidation-external heating method, respectively (Liu, 1996). The content of $CaCO_3$ was determined by using a gas volume method (Dreimanis, 1962; Zhao et al., 2016). The macroaggregate (>0.25 mm) measurement adopted the wet sieving method improved by Yoder (1936). The light and heavy fractions of organic carbon were separated in NaI solution with the density of 1.7 g cm^{-3} (Elliott, 1991).

LB method was used to measure the aggregate stability under three treatments: fast wetting (FW), slow wetting (SW) and mechanical breakdown by slaking after pre-wetting (WS) (Le Bissonnais, 1996). The soil samples were air dried and 3-5 mm aggregates were selected. The 3-5mm aggregates are dried in a 40 °C oven for

24 hours to ensure they are at the same matrix potential. Then the aggregates were treated in three different treatments. FW: the aggregates of 5 g were immersed in 50 mL deionized water, and the water was absorbed by pipette after 10 minutes. SW: the aggregates with 5 g were gently placed on the matric potential of -0.3 kPa for 30 minutes to ensure that the aggregates were wetted completely. SW: the aggregates of 5 g were immersed in 50 mL ethanol (95% in mass), and the ethanol was absorbed by pipette after 10 minutes. And then transferred the aggregates to a 250 mL flask filled with 200 cm^3 deionized water, corked and stirred up and down for 20 times, and the water was absorbed by pipette after 30 minutes. Transfer the soil aggregates from the above three treatments to a sieve (0.05 mm) already immersed in alcohol (95% in mass) and shake up and down 20 times. The aggregate retained in the sieve was baked for 48 hours in the oven at 40 °C. The dried aggregate was passed through the dry sieve of 3, 2, 1, 0.5, 0.25, 0.1 and 0.05 mm, and then measured for their size. Each treatment is repeated three times.

Aggregate stability is expressed in terms of mean weight diameter (MWD).

$$\mathrm{MWD} = \sum_{i=1}^{n} w_i x_i \qquad (1)$$

where w_i is the weight fraction of aggregates in size class i with an average diameter x_i.

2.4 Data analysis

The relative slaking index (RSI) and the relative mechanical breakdown index (RMI) were used to evaluate the sensitivity of aggregates to slaking and mechanical breakdown effects (Zhang & Horn, 2001).

$$\mathrm{RSI} = \frac{\mathrm{MWD_{SW}} - \mathrm{MWD_{FW}}}{\mathrm{MWD_{SW}}} \qquad (2)$$

$$\mathrm{RMI} = \frac{\mathrm{MWD_{SW}} - \mathrm{MWD_{WS}}}{\mathrm{MWD_{SW}}} \qquad (3)$$

where MWD_{FW}, MWD_{WS}, and MWD_{SW} are the mean weight diameter obtained by the FW, WS, and SW treatments, respectively (Le Bissonnais, 1996). The larger of RSI or RMI, the higher sensitivity of the aggregates to slaking or mechanical breakdown.

The splash erosion rate was the splashed-out soil mass from the test area per unit area per unit time, which can be calculated with Eq. (4):

$$D = \frac{S}{At} \qquad (4)$$

where D is the splash erosion rate (g m^{-2} min^{-1}), S is the mass of the splashed material (g), A is the test area (m^2) and t is the duration of the rain (min).

The rainfall kinetic energy was calculated by referring to the formula in Xiao et al. (2017; 2018). Alcohol and deionized water have different rainfall kinetic energy due to their characteristics. The raindrop parameters and rainfall kinetic energy are shown in Table 2.

All statistical analyses were performed by using Excel 2010 and SPSS 19.0. Soil aggregate stability indexes were analyzed with a variance analysis (ANOVA), and the others with the Pearson correlation analysis (i.e., splash erosion rate, contribution of slaking and mechanical striking, etc.).

3. Results

3.1 Aggregate stability indexes

The aggregate stability indexes for the five soils are shown in Figure 2. The MWD_{FW}, MWD_{WS} and MWD_{SW} ranged from 0.612 to 2.389, from 1.202 to 3.262, and from 1.935 to 3.367, respectively. The MWD values increased with the increase of SOC contents. The aggregate stability values increased in the order of MWD_{SW} >MWD_{WS} >MWD_{FW} for the five soils. It showed that the effect of chemical dispersion (SW) was the weakest of aggregate breakdown mechanisms, whereas slaking (FW) had the most effect on aggregate breakdown. The RSI and RMI decreased from 0.698 to 0.293, and from 0.325 to 0.033 with the increase of SOC, respectively. The value of RSI was larger than that of RMI for the five soils.

Figure 3 indicated that MWD_{FW}, MWD_{WS} and MWD_{SW} had significant positive correlations with SOC contents, but no significant positive correlation with LFOC and HFOC. They were negatively correlated with clay and the content of $CaCO_3$. MWD_{FW}, MWD_{WS} and MWD_{SW} had no significant positive relationships with the contents of free-form Fe, amorphous Fe, free-form Al and amorphous Al. RSI and RMI had significant negative correlations with the contents of SOC and LFOC, while they had no significant corrections with free-form Fe, amorphous Fe, free-form Al and amorphous Al contents.

3.2 Splash erosion rate

Splash erosion rate increased with the increase of rainfall kinetic energy for both deionized water and alcohol raindrops (Figure 4). The relationships for five soils could be described by power functions, and the coefficient of determination (R^2) was higher than 0.94 for both deionized water and ethanol tests (Table 3). The coefficient of power function can serve as an indicator of erosion severity with higher values reflecting higher soil erodibility.

The splash erosion rate has no significant negative correlations with SOC and HFOC in both deionized water and ethanol tests (Table 4). The negative and positive correlations were found between splash erosion rate and LFOC in deionized water and ethanol tests, respectively. An exception was that the negative correlation was found for ethanol tests in 1.5 m rainfall height. Meanwhile, compared with SOC and

HFOC, LFOC had weaker relations with splash erosion rate in deionized water tests.

3. 3 Macroaggregates

The macroaggregate (>0.25mm) contents remained in splash pan after rainfall in ethanol tests were more than that in deionized water tests (Figure 5). The macroaggregate contents for eroded soils were less than those of the parent soil for both deionized water and ethanol tests. However, the macroaggregate contents were increasingly closer to the parent soil with the increase of soil organic carbon contents, and the trend was more obvious in ethanol tests. The macroaggregate contents decreased with the increase of kinetic energy in both deionized water and ethanol tests, whereas the kinetic energy had no such significant effects in the ethanol tests except for soil sample IV.

The positive correlations were found between the macroaggregate contents and SOC, LFOC and HFOC in deionized water tests (Table 4). The correlations between macroaggregate and HFOC were weaker than those of SOC and LFOC. However, there were no significant correlations between them in ethanol tests.

3.4 Effects of slaking and mechanical striking on splash erosion

Figure 6 showed that the contribution rate of slaking and mechanical striking decreased from 75% to 25% and increased from 25% to 75% with the increase of rainfall kinetic energy, respectively. Meanwhile, when the rainfall kinetic energy was less than the range of critical values (between 9 J m^{-2} mm^{-1} and 12 J m^{-2} mm^{-1}), the contribution of slaking has dominant impact on aggregates disintegration. When the rainfall kinetic energy was greater than the range of critical values, the contribution of mechanical striking to splash erosion is gradually greater than that of slaking.

Table 4 indicated that the contribution rate of slaking had negative correlations with SOC contents when the kinetic energy increased from 3 to 12 J m^{-2} mm^{-1}, and it had positive correlations when the kinetic energy changed between 15 to 18 J m^{-2}

mm^{-1}. With the increase of the kinetic energy, the correlation coefficient decreased from -0.774 to 0.061. There were no significant correlations between the contribution rate of slaking and LFOC, meanwhile the correlation coefficient had an increasing trend with the increase of the kinetic energy. The correlations between contribution rate of slaking and HFOC was significantly negative when the kinetic energy increased from 3 to 6 J m^{-2} mm^{-1}. The correlation coefficient decreased from 0.900 to 0.671 with the increase of kinetic energy.

4. Discussion

Generally, soil clay, SOC, $CaCO_3$, and Fe/Al oxides act as cementing agents that affect the formation and stability of aggregates (An, Darboux, & Cheng, 2013; Dimoyiannis, 2012; Le Bissonnais., 1996; Le Bissonnais & Arrouays, 1997). The aggregate stability had significant positive correlation with SOC but not with the contents of clay, $CaCO_3$, and Fe/Al oxides (Figure 3). In this study, SOC acted as the main factor affecting the aggregate stability because the test soils had the similar contents of clay, $CaCO_3$, and Fe/Al oxides (Table 1). The SOC and LFOC had significantly negative correlations with RSI and RMI, illustrating that the sensitivity of slaking and mechanical striking decreased with increases of SOC and LFOC. Therefore, SOC, especially the LFOC, played an important role in resisting disintegration of aggregates. The formation of soil aggregate relies on organic materials, and the organic binding agents were mainly polysaccharides, roots and fungal hyphae, strongly sorbed natural polymers, and so on (Sdall & Oades, 1982). The roots and fungal in composition of LFOC could promote the formation of soil aggregate directly (Elliott, 1986; Oades, 1984). Thus, the aggregate stability and the organic binding agents increased with the content of LFOC.

The power function relationships between splash erosion rate and rainfall kinetic energy is consistent with the conclusions of the previous researchers (Hu, Zhen, &

Bian, 2016; Sharma, Gupta, & Rawls, 1991; Xiao et al., 2017; 2018). There was a tendency that splash erosion rate was negatively correlated with SOC, LFOC and HFOC for both deionized water and ethanol tests. However, the correlations were not statistically significant. This could be caused by the relatively narrow ranges of SOC, LFOC and HFOC used in this study, or splash erosion might be not as sensitive to SOC and LFOC as the aggregate sensitivity to slaking and mechanical breakdown effects.

Raindrops hit the soil surface with a certain kinetic energy, which is often sufficient to breakdown soil aggregates and compact the soil surface (Moss & Green, 1987). The deionized water raindrops had both slaking and mechanical striking effects on aggregate disintegration, whereas alcohol only had mechanical striking effects (Le Bissonnais, 1996). On the other hand, the kinetic energy of deionized water raindrops was greater than that of ethanol raindrops at the same fall height (Table 2). These results lead to the destructive capacity of deionized water raindrops were greater than that of ethanol.

The mechanical striking of raindrops on soil could be greatly reduced by vegetation cover (Lal, 1976; Adekalu, Olorunfemi, & Osunbitan, 2007; Kukal & Sarkar, 2010). However, vegetation could promote the accumulation of SOC, especially the LFOC in short term (Boone, 1994; Garcia, Hemanderz, Roldan, & Martin, 2002; Gil-Sotres, Trasar-Cepeda, Leiros, & Seoane, 2005). That resulted in the increase of aggregate stability (Figure 2), and counteracted the increase of slaking contribution. Finally, vegetation coverage could improve soil antierodibility by reducing both slaking and mechanical striking effects of raindrops.

There are some limitations for testing five soils developed from only one parent. The effects of SOC on soil aggregates disintegration may be different for different soil types due to interactive effects of other factors. Furthermore, the coupled effects of other factors in aggregate breakdown during splash erosion also need to be researched in the future.

5. Conclusions

In this study, the simulated rainfall experiments for five soils with different SOC were carried out. The results indicated that the content of SOC and LFOC had substantial effects on aggregate stability. The RSI and RMI decreased as SOC and LFOC increased. The amount of macroaggregates in deionized water tests were significantly less than that in alcohol tests under the same rainfall heights. The reduction of macroaggregates in eroded soil gradually decreased with the increase of SOC and LFOC, especially in alcohol test. As the rainfall kinetic energy increased, the contribution of slaking to soil splash decreased while the contribution of mechanical striking increased. The range of critical values between 9 J m^{-2} mm^{-1} and 12 J m^{-2} mm^{-1} were found to determine the dominated contribution of slaking and mechanical striking to splash erosion.

Data sharing: Research data are not shared.

Conflict of interest: none

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Tables

Tab.1 Basic physical-chemical properties of five test soils in the experiments

Soil samples	Year of vegetation restoration / a	Longitude and latitude	Clay / %	Silt / %	Sand /%	$CaCO_3$/ g kg^{-1}	Soil moisture content/ %	Soil organic carbon/ g kg^{-1}	Light fractions of soil organic carbon/ g kg^{-1}	Heavy fractions of soil organic carbon/ g kg^{-1}	pH (1:2.5)	Free-form Fe/g kg^{-1}	Amorphous Fe/g kg^{-1}	Free-form Al/g kg^{-1}	Amorphous Al/g kg^{-1}
I	3	N36°03.61′, E109°08.99′	22.36	21.16	56.48	81.09	2.46	7.54	5.89	1.68	8.51	5.10	0.48	1.57	0.58
II	20	N36°03.60′, E109°09.03′	23.54	25.23	51.23	82.53	1.18	13.34	10.45	2.86	8.36	7.91	0.45	0.73	1.17
III	100	N36°04.94′, E109°08.71′	20.18	29.63	50.20	77.63	0.72	14.85	9.83	4.99	8.42	8.93	0.64	0.56	1.31
IV	80	N36°03.68′, E109°08.87′	21.05	18.06	60.88	76.76	1.30	18.39	15.70	2.66	8.25	6.16	0.81	1.87	1.63
V	55	N36°03.85′, E109°08.78′	22.12	15.84	62.04	79.98	0.92	21.69	17.88	3.78	8.37	4.66	0.39	1.70	0.44

Tab. 2 Rainfall kinetic energy for different fall heights

Liquid	Fall height/m	Time for 10 raindrops/s	Weight of 10 raindrops/g	Mean raindrop diameter/mm	Rainfall kinetic energy/J m^{-2} mm^{-1}
Deionized water	0.5	9.91	0.09	2.62	1.77
	1.0	9.91	0.09	2.63	6.15
	1.5	9.91	0.09	2.62	12.06
	2.0	9.92	0.09	2.63	18.75
Ethanol	0.5	6.45	0.04	2.03	1.49
	1.0	6.23	0.04	2.03	5.00
	1.5	6.34	0.04	2.03	8.90
	2.0	6.29	0.04	2.03	13.06

Tab. 3 Nonlinear regression between rainfall kinetic energy and splash erosion rate in simulated rainfall tests by using deionized water and ethanol as raindrop

Number of soil samples	Deionized water raindrop	R^2	Ethanol raindrop	R^2
I	$D = 1.1959\ e^{1.15}$	0.97	$D = 0.3055\ e^{1.38}$	0.98
II	$D = 2.2951\ e^{0.89}$	0.99	$D = 0.5391\ e^{1.27}$	0.99
III	$D = 0.7207\ e^{1.18}$	0.99	$D = 0.2026\ e^{1.51}$	0.98
IV	$D = 1.8037\ e^{1.03}$	0.97	$D = 0.5753\ e^{1.19}$	0.94
V	$D = 0.6303\ e^{1.26}$	0.99	$D = 0.2111\ e^{1.41}$	0.96

Notes: D is the soil splash rate (g m^{-2} min^{-1}) and e is the rainfall kinetic energy (J m^{-2} mm^{-1})

Tab. 4 Pearson correlation coefficients between soil organic carbon and its fractions related to the splash erosion rate, contribution of slaking and macroaggregates (>0.25mm) contents

	Splash erosion rate								Contribution of slaking						Macroaggregates (>0.25mm) contents							
	Deionized water				Ethanol										Deionized water				Ethanol			
	$D_{0.5}$	$D_{1.0}$	$D_{1.5}$	$D_{2.0}$	$D_{0.5}$	$D_{1.0}$	$D_{1.5}$	$D_{2.0}$	C_3	C_6	C_9	C_{12}	C_{15}	C_{18}	$W_{0.5}$	$W_{1.0}$	$W_{1.5}$	$W_{2.0}$	$W_{0.5}$	$W_{1.0}$	$W_{1.5}$	$W_{2.0}$
SOC	-0.251	-0.270	-0.310	-0.513	-0.036	-0.031	-0.502	-0.026	-0.774	-0.334	-0.126	-0.005	0.016	0.061	0.632	0.429	0.616	0.656	0.083	0.036	-0.144	-0.016
LFOC	-0.158	-0.086	-0.131	-0.363	0.095	0.056	-0.490	0.120	-0.623	-0.129	0.072	0.188	0.201	0.245	0.616	0.431	0.606	0.619	0.177	-0.129	-0.072	0.050
HFOC	-0.468	-.0822	-0.818	-0.791	-0.525	-0.353	-0.263	-0.576	-0.900*	-0.918*	-0.802	-0.733	-0.692	-0.671	0.316	0.163	0.289	0.408	-0.328	-0.349	-0.343	-0.267

Note: $D_{0.5}$, $D_{1.0}$, $D_{1.5}$, $D_{2.0}$ is splash erosion rate at different fall heights (0.5m, 1.0m, 1.5m and 2.0m), respectively; C_3, C_6, C_9, C_{12}, C_{15} and C_{18} is the contribution of slaking in different rainfall kinetic energy (3, 6, 9, 12, 15 and 18 J m^{-2} mm^{-1}), respectively. SOC, LFOC and HFOC is soil organic carbon, light fractions organic carbon and heavy fractions organic carbon content, respectively. $W_{0.5}$, $W_{1.0}$, $W_{1.5}$ and $W_{2.0}$ is the contents of >0.25mm water stable aggregates at different heights (0.5m, 1.0m, 1.5m and 2.0m).

* Significant at 0.05 level of probability.

Figure captions

Figure 1. Schematic representation of the experiment device

Figure 2. Aggregates water-stability of five loessial soils developed from same parent material with different soil organic carbon (SOC) contents. The SOC contents of I, II, III, IV, and V is 7.54, 13.34, 14.85, 18.39, 21.69 g kg-1, respecti Different letters in the same set of data of the same color indicate significant differences at 5% level.

Figure 3. Heatmap for the relationships between soil aggregate stability indexes and soil properties. MWD_{FW}, MWD_{WS} and MWD_{SW} denote the mean weight diameters obtained after the fast-wetting (FW), pre-wetting and stirring (WS and slow wetting (SW), respectively; RSI and RMI denote relative slaking index and relative mechanical breakdown index, respectively; SOC, LFOC and HFOC denote soil organic carbon, light fractions organic carbon and heavy fractions organic carbon content, respectively.

Figure 4. Relationships between rainfall kinetic energy of two kind of raindrops (A is deionized water; B is ethanol) and splash erosion rate. I, II, III, IV and V were five different tested soils, which were developed from the same similar physicochemical properties and different organic carbon content because of different vegetation restoration time.

Figure 5. The contents of macroaggregates (>0.25mm) in parent soil an remained in splash pan after rainfall at different height (0.5, 1.0, 1.5, and 2.0 m) with different raindrops (A is deionized water; B is ethanol). Different letters in the same group of each soil sample indicate significant differences at the 0.05

level.

Figure 6. Changes of contribution rate of slaking and mechanical striking (S is the contribution rate of slaking; M is the contribution rate of mechanical striking) to splash erosion with rainfall kinetic energy. I, II, III, IV and V were five different tested soils, which were developed from the s physicochemical properties and different organic carbon conten different vegetation restoration time.