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Full Length Article

Effect of Biochar on Soil Aggregates in the Loess Plateau: Results from Incubation Experiments

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ABSTRACT

Soil aggregates were chosen as the indices of soil structure and stability to detect the effects of biochar on the four typical types of soils in the Loess Plateau. After 11 months pot incubation experiments with four application rates i.e., 0, 4, 8 and 16 g kg^{-1} biochar, undisturbed soils were sampled and passed through the dry-sieving and wet-sieving, respectively. The biochar application can increase soil water-stable aggregate content of both Dark Loessial soil and Lou soil which were classified as silt loam soils, while only improved aggregate formation of Dark Loessial soil. No significant influence was detected in the soil aggregate formation and stability of the Loessal soil and Shahuang soil, which were classified as sandy loam soils. Biochar application could represent a useful practice to enhance soil aggregates of silt loam soils and a potential method to increase the soil stability and decrease the soil erosion. © 2012 Friends Science Publishers

Key Words: Biochar; Soil amendment; Soil aggregate distribution; Soil water-stable aggregate; Loess plateau

INTRODUCTION

Soil structure exerts important influences on soil physical, chemical, and biological processes (Bronick & Lal, 2005). It is a key factor influencing the transport of water, the germination and the growth of plants (Braunack & Dexter, 1989; Pirmoradian *et al.*, 2005; Wei *et al.*, 2006; An *et al.*, 2008).

Aggregation results from the rearrangement of particles through flocculation and cementation. It is an important soil functional unit for maintaining soil porosity and providing stability against soil erosion (Barthès & Roose, 2002; Cantón *et al.*, 2009). Aggregate stability is used as an indicator of soil structure (Six *et al.*, 2000; Bronick & Lal, 2005). Soil organic carbon (SOC) acts as a binding agent and is the key constituent in the formation of aggregates (Tisdall & Oades, 1982; Bronick & Lal, 2005; An *et al.*, 2008). The loss of organic materials caused by long-term cultivation appears to be a primary mechanism of the degradation of soil aggregates (Jastrow, 1996). Organic matter as important soil additives have positive effects on improving soil properties. The effects of organic matter on the soil aggregation had studied intensively (Piccolo & Mbagwu, 1990; Jastrow, 1996; Wei *et al.*, 2006; Wortmann & Shapiro, 2008; Abiven *et al.*, 2009; Alagöz & Yilmaz, 2009).

Biochar as a kind of organic matter has been used as soil amendment to improve soil structures and fertility qualities (Glaser *et al.*, 2002; Atkinson *et al.*, 2010). Glaser *et al.* (2000) showed that a large proportion of biochar in terra preta was present in unprotected fractions. However, Brodowski *et al.* (2006) found that biochar was associated mainly with the very fine, sub-50 μm soil fraction and Liang *et al.* (2008) demonstrated that biochar was predominately present in small clusters of soil particles or soil aggregates, rather than as free organic matter. Brodowski *et al.* (2006) also observed that the small proportion of biochar particles in soil occurred in the large macro-aggregate fractions (> 2 mm) and biochar might act as a binding agent for organic matter in aggregate formation and then protect against degradation (Brodowski *et al.*, 2006; Saran *et al.*, 2009). Biochar may influence soil aggregates and its stability due to the interactions with soil organic matter, microorganisms and minerals (Piccolo *et al.*, 1997; Verheijen *et al.*, 2009). The slow oxidation properties of biochar determine the long term effect on soil aggregation (Verheijen *et al.*, 2009).

The effects of biochar on soil properties are influenced by many factors, such as the feedstock, procedure process, and the soil basic characteristic. Some research has shown the converse results of biochar's impact on soil aggregates. Busscher *et al.* (2010) found that adding biochar without switchgrass did not improve soil aggregation or infiltration rate and the interaction between the biochar and switchgrass was not significant at $P < 0.05$. Peng *et al.* (2011) showed

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that amendment of 1% biochar had no effect on soil aggregate stability and the temperature-dependent trend was not observed for aggregate stability.

The specific mechanism that biochar exerts on water retention, macro-aggregation and soil stability are poorly understood (Saran *et al*., 2009). Caution should be taken when applying biochar into soils, which were susceptible to water erosion (Peng *et al*., 2011). The Loess Plateau is the most serious region of soil erosion in the world. In the area, soil structure holds a vital role in the agriculture production and ecology restoration. Soil water-stable aggregation research is always conducted in relation to soil erosion on the Loess Plateau and the content of soil water-stable aggregates is the best factor reflecting the ability of a soil to resist erosion on the Loess Plateau (An *et al*., 2008).

Four typical soil types in the Loess Plateau and one type of biochar were chosen as test materials for incubation experiments to investigate the effects of biochar on soil aggregates distribution and stability. Potential positive effects of biochar on soil stability if proved it could be widely used in the soil erosion zone to prevent soil degradation in agricultural production and to promote the ecology restoration.

MATERIALS AND METHODS

Biochar: Biochar used in the experiment was bought from Yonghong Charcoal Factory, located in Hu County, Shaanxi Province, China. The original materials, sawdust from Chinese pine and locust, were packed in a traditional charcoal kiln made of brick and mud, then pyrolysed at the final temperature of approximately 660°C. After almost 2 h carbonization, the production was allowed to cool down to ambient temperature. For the incubation experiment, the biochar mass was ground to pass 2 mm. The subsamples were ground to pass 1 mm and 0.25 mm respectively, used for the properties determination of biochar. The biochar had C and N contents of 66.27% and 2.21%, respectively, a total ash content of 12.50%, a pH (H_2O) of 8.38 and CEC (cation exchange capacity) of 31.28 cmol kg^{-1}.

Soils: Shahuang soil (M soil), Loessal soil (H soil), Dark Loessial soil (B soil) and Lou soil (L soil) in the Loess Plateau were collected from the 0-20 cm horizon. After air-drying for five days, the soil was ground to pass 2 mm sieve for the incubation experiment. The subsamples were ground to pass 1 mm and 0.25 mm respectively, used for the properties determination of the four soils. The properties of the soils used in the experiment are listed in Table I. All samples were analyzed in duplicate; the means results can be observed in the tables.

Incubation experiment and sampling: In order to compare the different effects of biochar on four different soils, pot trails with four soil treatments per soil type were designed. The pots were made by the polyvinyl chloride (160 mm diameter, 220 mm deep). The treatments were as follows: unamended soil, soil with biochar 4 g kg^{-1}, 8 g kg^{-1} and 16 g kg^{-1}. Then the pots were filled with each soil mixture to 20 cm height at bulk density designed. The bulk density of M, H, and B soils were 1.3 g cm^{-3}, and that of L soils was 1.2 g cm^{-3}. Each treatment was replicated in triplicate. The trial was located in the institute of soil and water conservation, Yangling, Shaanxi Province, China. Soil moisture was adjusted to 60% - 70% of water holding capacity every five to six days in all columns and no water was leached out from the pots.

We collected the soil samples from 0-10 cm depth in November, 2011. The undisturbed soil sampling used for soil aggregate analysis was divided into less than 10 mm and air-dried until analysed.

Measurements of soil aggregates: Dry-sieving method was used to assess the distribution of soil aggregates (Institute of Soil Science, 1978). The procedure is as follows: 300 g air-dried soil was put on the top of a set of sieves with an opening of 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mm diameters from top to bottom, and then shaking at about 60 times min^{-1} for 10 min. The weight of the soil sample on each sieve was determined. And the soil aggregate content of each size is calculated following the formula:

$$R_n = \frac{W_n}{300}$$

Where R_n stands for the soil aggregate content of each size sieve (%); W_n stands for the weight of the soil aggregate of each sieve size (g).

Wet-sieving method was used to assess the stability of soil aggregates (Institute of Soil Science, 1978). After the air-dried soils were wetted for about half an hour with distilled water, the soil was immersed in water on a set of five nested sieves (5, 2, 1, 0.5 & 0.25 mm) and then shaken vertically about 3cm for 1 minute (about 30 times). The aggregates retained on each sieve were washed into the numbered bottles and dried with a sand oven. Then weighted and got the amount of aggregates in each sieve.

Three parameters were chose to evaluate the effects of biochar on soil aggregate stability: Soil water-stable aggregate content, MWD (Mean Weight Diameter), GMD (Geometric Mean Diameter). The formulas for calculating MWD and GMD are as follows:

$$MWD = \frac{\sum_{i=1}^{n} (\overline{x_i} w_i)}{\sum_{i=1}^{n} w_i}$$

$$GMD = Exp\left[\frac{\sum_{i=1}^{n} w_i \ln \overline{x_i}}{\sum_{i=1}^{n} w_i}\right]$$

Where $\bar{x}_i$ is the mean diameter between the two sieves (mm); and w_i is the weight fraction of aggregates remaining on the sieve (%).

Data analysis: All data gathered in the research were recorded and classified in the Microsoft Office Excel 2003. The effects of biochar on different soils aggregates with biochar application ratios were examined by a one-way analysis of variance (ANOVA). Analyses of variance were carried out by SPSS16.0.

RESULTS

Soil aggregates distribution: The application of biochar has the potential to influence the soil aggregation distribution. The different effects were influenced by soil types, biochar application rates and layers (Table II).

For the M and H soils, there was no difference between the control and the 4, 8, 16 g kg^{-1} biochar amendment treatments for all the aggregate sizes. The non-significant influences could also be found in the > 0.25 mm and > 2 mm aggregates.

For the B soil, all the biochar application treatments showed the increasing effect for the 1-2 mm, 0.5-1 mm and > 0.25 mm. However, significant differences were observed in 8 g kg^{-1} treatment only.

For the L soil, the increase in the amount of biochar resulted in decreasing aggregate content. This was significant in case of 7-10, 5-7, 3-5, 2-3 and 1-2 mm aggregates.

Soil water-stable aggregates: The effect of biochar on soil aggregation stability of different soil types is shown in Table III. Biochar application had no significant effect on the soil aggregation stability of the M soil. All the indices of the > 0.25 mm aggregates, MWD, GMD showed non-significant difference between the treatments means and the control. However, the 4 and 8 g kg^{-1} biochar application treatments of all the aggregates sizes always got the lower water-stable aggregate content when compared with the control and 16 g kg^{-1} treatments.

All the biochar treatments of the H soil did not get any significant influence on the water-stable aggregate content, except the 4 g kg^{-1} treatment for the 2-5 mm aggregates.

For the B soil, all the aggregate sizes of biochar amended soils got the increasing effect except the 2-5 mm aggregates. And the significant increasing effects were detected in all the treatments for > 0.25 mm aggregates, 8 and 16 g kg^{-1} treatments for the > 5 mm aggregates, 16 g kg^{-1} for the 0.5-1 mm aggregates and 8 g kg^{-1} for 1-2 mm aggregates. The water-stable aggregate content of the > 5 and > 0.25 mm increased gradually followed by the increase of biochar application rate. The significant increasing effects of MWD and GMD were observed in the 8 and 16 g kg^{-1} treatments. For the > 2 mm size group, the water-stable aggregate content increased followed by the increase of biochar application rate, and the 16 g kg^{-1} treatment showed significantly higher contents than the control.

Table I: Physico-chemical characteristics of the soils

Parameter	M	H	B	L
Sand (%)	32.48	36.18	17.35	7.97
Silt (%)	61.76	57.70	68.85	78.90
Clay (%)	5.75	6.12	13.80	13.13
Texture	Sandy loam	Sandy loam	Silt loam	Silt loam
OC (g kg^{-1})	2.33	3.42	6.31	7.12
N (g kg^{-1})	0.30	0.42	0.69	0.76
pH (1:2.5H_2O)	8.76	8.82	8.71	8.66
CEC (cmol·kg^{-1})	8.05	8.60	13.95	22.43

M: Shahuang soil; H: Loessal soil; B: Dark loessial soil; L: Lou soil. OC: Organic carbon content; CEC: Cation exchange capacity

The 8 and 16 g kg^{-1} biohcar application rate had the significant increasing effect on the water-stable aggregate content of > 5 mm and > 2 mm aggregates of L soil, While the 4 g kg^{-1} treatment decreased 2-5 mm aggregates.

DISCUSSION

Based on the basic properties of the 4 soils (Table I), the M and H soils were classified as sandy loam soils and B and L soils as silt loam soils. Biochar application has little effect on the soil aggregate distribution and the water-stable aggregate content of the M and H soils. Similar results of Busscher *et al*. (2010) proved that adding biochar did not improve aggregation in the loamy sands after 70 days incubation.

The biochar application only increased soil aggregation formation of the B soil. However, both of the B and L soil got the significant increasing effects on the total content of soil water-stable aggregates. Compared with that of the sandy loam soils, the biochar application could influence the condition of soil aggregation of the silt loam soils, and increase the water-stable aggregates content, especially. The effect increased with the increasing of biochar application rate (Table II & III). Higher soil aggregate stability has significant effects on reducing runoff and soil erosion hazards (Zhang *et al*., 2007). Thus, the biochar application into silt loam soils had the potential effect on decreasing soil erosion, especially at high biochar application rate.

The biochar used in the research is passed through the 2 mm sieve, so the content of soil aggregates which is higher than 2 mm can eliminate the influences of biochar particles and stand for the real changing of aggregate content influenced by biochar application. From Table III, we can conclude that the biochar can effectively combine with B and L soils better and form the higher content of soil water-stable aggregates at the higher biochar application rate.

The different effects of biochar on the two classes of soil may result from the different soil compositions which could influence the properties of biochar. Biochar in soil is refractory but not inert. Most of the effects of biochar on soil conditions are influenced by the oxidation productions of biochar, such as acidic function groups and humic materials (Cheng *et al*., 2006). Biochar incorporated into the soil would change gradually into stable humus (Topoliantz *et al*., 2006; Brodowski *et al*., 2007).

Table II: Effect of biochar on soil aggregation distribution (%)

	Percentage of soil aggregates (%)									
Treatments	**Aggregate size(mm):: >10**	**7-10**	**5-7**	**3-5**	**2-3**	**1-2**	**0.5-1**	**0.25-0.5**	**>0.25**	**>2**
M0	24.16 a	6.60 a	3.80 a	3.12 a	0.75 a	2.49 a	5.53 a	3.99 a	50.44 a	38.44 a
M4	21.72 a	5.77 a	3.90 a	3.43 a	0.87 a	2.29 a	5.20 a	4.20 a	47.39 a	35.70 a
M8	25.19 a	6.17 a	3.40 a	2.57 a	0.60 a	1.62 a	4.36 a	4.25 a	48.16 a	37.93 a
M16	22.90 a	7.61 a	3.90 a	2.93 a	0.63 a	2.08 a	4.86 a	4.14 a	49.06 a	37.98 a
H0	35.66 a	6.48 a	3.29 a	2.69 a	0.52 a	1.38 a	3.10 a	2.89 a	56.00 a	48.63 a
H4	26.43 a	5.79 a	3.07 a	2.76 a	0.58 a	1.56 a	3.85 a	3.40 a	47.44 a	38.63 a
H8	36.47 a	5.43 a	3.29 a	2.60 a	0.65 a	1.63 a	3.36 a	2.99 a	56.43 a	48.44 a
H16	33.87 a	6.52 a	3.52 a	2.79 a	0.56 a	1.43 a	3.40 a	3.27 a	55.36 a	47.27 a
B0	31.47 a	7.20 a	3.69 a	3.27 ab	1.15 a	4.50 b	10.44 a	7.22 a	68.94 a	46.78 a
B4	34.06 a	7.23 a	3.51 a	3.55 a	1.07 a	4.77 b	10.43 a	7.06 a	71.66 a	49.41 a
B8	27.48 a	8.17 a	4.37 a	3.70 a	1.19 a	5.91 a	12.17 a	7.55 a	70.55 a	44.91 a
B16	34.32 a	7.04 a	3.62 a	2.95 b	1.02 a	5.42 ab	11.16 ab	7.12 a	72.65 a	48.95 a
L0	30.19 b	7.02 a	3.64 a	3.24 a	1.35 a	9.59 a	16.87 a	9.33 a	81.24 a	45.45 a
L4	33.93 ab	5.76 ab	3.24 ab	2.52 b	0.99 b	5.49 cd	14.95 ab	10.51 a	77.38 a	46.43 a
L8	44.01 a	4.83 bc	2.22 c	2.08 c	0.63 cd	4.40 e	12.58 b	9.17 a	79.92 a	53.77 a
L16	34.08 ab	5.01 bc	2.70 bc	2.18 c	0.79 bc	6.85 bc	15.98 ab	10.73 a	78.32 a	44.76 a

Table III: Effect of biochar on soil water-stable aggregates (%)

	Percentage of soil aggregates (%)								
Treatments	**Aggregate size(mm): >5**	**2-5**	**1-2**	**0.5-1**	**0.25-0.5**	**>0.25**	**MWD**	**GMD**	**>2**
M0	0.22 a	0.32 a	2.43 a	4.57 a	5.29 a	12.82 a	0.33 a	0.28 a	0.53 a
M4	0.05 a	0.22 a	2.18 a	4.54 a	5.10 a	12.08 a	0.32 a	0.28 a	0.26 a
M8	0.17 a	0.30 a	1.98 a	4.33 a	4.70 a	11.48 a	0.32 a	0.28 a	0.48 a
M16	0.25 a	0.50 a	2.88 a	5.16 a	4.75 a	13.54 a	0.35 a	0.29 a	0.75 a
H0	0.47 a	0.75 a	2.66 ab	4.71 a	5.30 a	13.89 a	0.36 a	0.29 a	1.22 a
H4	0.72 a	0.37 b	2.04 b	4.03 a	4.16 a	11.33 a	0.35 a	0.28 a	1.09 a
H8	0.13 a	0.71 a	3.12 a	4.61 a	4.99 a	13.57 a	0.35 a	0.29 a	0.85 a
H16	0.07 a	0.52 ab	2.09 b	4.32 a	5.27 a	12.27 a	0.32 a	0.28 a	0.59 a
B0	2.42 cd	2.52 a	7.88 b	12.70 b	9.10 a	34.62 c	0.62 c	0.40 c	4.94 b
B4	2.93 bc	2.13 a	9.67 ab	14.43 ab	9.34 a	38.50 b	0.66 bc	0.42 bc	5.05 b
B8	4.05 b	2.28 a	10.03 a	13.83 ab	9.16 a	39.35 b	0.72 b	0.43 b	6.33 b
B16	6.56 a	2.37 a	9.75 ab	15.92 a	9.45 a	44.06 a	0.85 a	0.48 a	8.93 a
L0	0.89 b	2.64 ab	12.44 a	19.24 ab	12.66 a	47.87 a	0.65 ab	0.45 a	3.53 b
L4	0.25 b	1.24 c	9.27 a	22.36 a	13.96 a	47.08 a	0.55 b	0.42 a	1.49 b
L8	4.42 a	2.54 ab	9.38 a	18.59 b	14.04 a	48.97 a	0.77 a	0.47 a	6.96 a
L16	3.66 a	2.77 a	11.82 a	20.21 ab	11.85 a	50.31 a	0.78 a	0.49 a	6.43 a

Within a column of the same soil type, treatment means followed by different letters are significantly different at $P < 0.05$. M: Shahuang soil; H: Loessal soil; B: Dark loessial soil; L: Lou soil; MWD: Mean Weight Diameter; GMD: Geometric Mean Diameter

Previous research has shown that the humic substances could be used as soil conditioners to increase aggregate stability (Piccolo & Mbagwu, 1990; Piccolo *et al*., 1997; Imbufe *et al*., 2005) and that may be interpreted by the formation of soil clay-humic complex by the humic substances (Piccolo *et al*., 1997). The oxidation of biochar itself is slow, but some research showed that the organic matter addition can promote the oxidation of both biochar and the added organic materials (Liang *et al*., 2010; Novak *et al*., 2010; Awad *et al*., 2012). The oxidation of biochar in the B and L soils with the higher soil organic matter (about 2 times than that of the H & M soils, shown in Table I) may be faster, forming more humic materials in the incubation period, and increase the stability of soil aggregates.

Tisdall and Oades (1982) had reported that root and fungal hyphae as the temporary organic binding agents can initiate macroaggregate formation by enmeshing fine particles into macroaggregates and stabilize macroaggregates. The biochar application have the potential effects to promote soil microbe living (Lehmann *et al*., 2011) and indirect effects on mycorrhizae through effects on other soil microbes (Warnock *et al*., 2007). The better basic properties, such as the higher organic carbon content, would provide the better living condition for soil microbes. These can partly interpret the increasing effect of biochar on the soil aggregate formation and stability of B soil.

The improvement of soil aggregates is a long process. Although the increasing effect of soil aggregates was found in the B and L soils after 11 months incubation, the soil macro-aggregates content and water-stable aggregate content were both in the low level. The soil water-stable aggregate content of the soil with well structure should be more than 70%, but the B and L soils were just about 40%-50%. The positive effect of biochar on soil aggregates is limited in the short incubation period.

To conclude, in a short incubation period, biochar application had little effect on the improvement of soil aggregates formation, while increased the soil aggregate stability of silt loam soils (B & L soils). The higher application rate of biochar might get the significant increasing effect. But to the sandy loam soils (H & M soils), which have low organic matter content and widely spread in the Loess Plateau and easily been eroded, no positive effect was detected. The biochar application methods should be modified before using as the soil structure amendment to increase soil stability and decrease soil erosion, especially in the sandy loam soils. Further work is needed to determine the effects of other types of biochar and biochar application with plant growth.

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