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Effect of Biochar on pH of Alkaline Soils in the Loess Plateau: Results from Incubation Experiments

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ABSTRACT

An incubation experiment was conducted to determine the effects of biochar on the pH of alkaline soils. Five types of alkaline soils collected at the Loess Plateau and one type of biochar with a slightly lower pH than the soils were used. After incubation for 4 months and 11 months, the control soil and biochar-amended soils (4, 8 & 16 g of biochar/kg of soil) were sampled and tested. The application of alkaline biochar did not increase the soil pH but instead produced a decreasing pH trend, especially with higher biochar application rates. The decrease in soil pH was more significant at the 10 cm to 20 cm layer than in the 0 cm to 10 cm layer. The F soil type (Aeolian sandy soil), which had the highest pH, showed the largest decrease in pH after 11 months of incubation. Acidic materials produced by the oxidation of biochar and organic matters may have caused the pH decrease. The high soil cation exchange capacity caused by the biochar application might restrict the soil salinization process to some extent. © 2012 Friends Science Publishers

Key Words: Biochar; Alkaline soil; Soil pH; Loess plateau

INTRODUCTION

Biochar is a material produced from organic matter under high temperature and low oxygen conditions. In recent years, scientific attention has been focused on its effect on soil amendment and ecological restoration. The pyrolytic process converts biomass acids into the bio-oil component and the alkalinity is inherited by the solid biochar (Laird *et al*., 2010; Yuan & Xu, 2011). Inorganic carbonates and organic anions are alkaline components in biochar (Yuan *et al*., 2011c). When biochar is produced at different temperatures, their alkalinity increases with increasing charring temperature (Mukherjee *et al*., 2011; Yuan *et al*., 2011c).

The alkaline substances in biochar are more easily released into the soil compared with its feed stock when biochar samples are incubated with the soil (Yuan *et al*. 2011b). The liming effect of biochar on acidic Ultisols had been confirmed by Yuan and Xu (2011) and Yuan *et al.* (2011b). Glaser *et al.* (2001; 2002) indicated that the application of biochar can increase the pH in highly weathered tropical soil. The alkalinity of biochars was a key factor affecting their liming potential (Yuan *et al*., 2011b). When biochar with higher pH value was applied to the soil, the amended soil generally became less acidic (Yuan *et al*., 2011c). The ameliorating effects of biochar on soil pH clearly increased with increasing biochar application rates (Yuan *et al*., 2011a). The improvement of crop growth from biochar amendment of a typical Ultisol may result from an increase of pH and cation exchange capacity (CEC) (Peng *et al*., 2011).

The pH of biochar, similar with the other properties, is influenced by the type of feedstock, production temperature, and production duration. At the same production temperature of 300°C, the biochar produced from corn straw, peanut straw, and soybean straw were all alkaline, but the pH of biochar from canola straw, wheat straw, and hull straw was 6.48, 6.42 and 6.43, respectively (Yuan & Xu, 2011; Yuan *et al*., 2011c). The biochar made at 350°C by Cheng *et al.* (2006) also demonstrated low pH at 5.38 in water. The different pH values between biochar and soil may be the main reason for soil pH change. Acidic biochar could also increase soil pH when used in soil with lower pH value. When biochar with a pH value of 5.38 was added into soil with a pH value of 4.33 and incubated at 30°C for 4 months, the soil pH increased (Cheng *et al*., 2006).

There are only a few studies focusing on the effect of biochar on the pH of alkaline soil. In the research conducted by Van Zwieten *et al*. (2010), the application of biochar 1 with pH value of 9.4 and biochar 2 with pH value of 8.2 both increased the pH of Ferrosol (initial pH at 4.2), but only biochar 2 increased the pH value of Calcarosol (initial

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pH at 7.67). When biochar was used in mine tailing soil, the pH value of 8.13 was increased to 10.2 at 10% biochar application rate (Fellet *et al.*, 2011). The research by Yuan *et al.* (2011a) showed that the pH of biochar-amended acidic Ultisold decreased with increasing incubation duration, even though the pH was still higher than that of the control. The production of acidic functional groups from the oxidation of biochar was identified to have decreased the soil pH in the incubation process (Cheng *et al.*, 2006).

The Loess Plateau is located in a semi-arid region. The poor soil fertility and soil water-retention capacity have become major restriction factors of local agricultural production and ecological restoration. The ameliorating effects of biochar on soil water condition and soil fertility have been confirmed in many regions, which make biochar a kind of amendment material for the soil in the Loess Plateau. Most of the soils in the Loess Plateau are alkaline, with pH values ranging from 8 to 9 or even higher. The pH level of alkaline soils would be affected by biochar application and the possible increase of soil pH in alkaline soil is harmful for plant growth.

Five typical soil types in the Loess Plateau and one type of biochar were chosen as test materials for incubation experiments investigating the effect of biochar on soil pH of alkaline soils. The different effects caused by biochar application rate, soil depths and different incubation durations were also determined. Additional procedures are required to decrease the effects of biochar application as soil amendment material if soil pH is promoted by the presence of biochar. However, if the pH increase was not significant, biochar could be used in the region without increasing soil alkalinity.

MATERIALS AND METHODS

Biochar: Biochar used in the experiment was produced from Chinese pine and locust at the final temperature of approximately 600°C for almost 2 h. The biochar was ground and filtered through a 2 mm sieve for the incubation experiment.

Soils: Five contrasting soil types spread across the Loess Plateau were collected from 0 cm to 20 cm horizons as test objects in the incubation experiment. Lou soil (L soil) was collected at Wu gong County, Shaanxi, China (N 34°25′27.0″, E 108°04′22.1″). Dark Loessial soil (B soil) was collected at Luochuan County, Shaanxi, China (N35°42′54.6″, E109°22′59.8″). Loessal soil (H soil) was dug atAnsai County, Shaanxi, China (N 36°51′06.7″, E 109°18′45.6″). Shahuang soil (M soil) was collected at Suide County, Shaanxi, China (N 37°38′26.6″, E 110°13′05.5″). Aeolian sandy soil (F soil) was sourced from Jinjie District, Shenmu County, Shaanxi, China (N 38°46′53.4″, E 110°15′06.4″). After air-drying for about 5 days, the soil was ground to pass through a 2 mm sieve. Discernible plant litter and rock were removed during sieving.

Incubation experiment: Four treatments for all of the five soil types were designed and replicated six times for the incubation experiment. The treatments were as follows: untreated soil, soil with 4 g kg^{-1}, 8 g kg^{-1} and 16 g kg^{-1} biochar by weight (C_0, C_4, C_8 & C_{16}, respectively). After mixing the biochar with the soil at the designated amount, the soil was added into incubation pots, which were made of polyvinyl chloride tube (160 mm in diameter & 220 mm in depth). The bulk densities of the five soils were determined differently according to the field condition of each soil type. For the L soil, 1.2 g $cm^{-3}$was chosen, 1.3 g cm^{-3} for B, H, and M soils and 1.6 g cm^{-3} for F soil. The 20 cm thick soil in each column was packed in four 5 cm layersto achieve soil consistency with equal bulk density. The calculated amount of soil in each layer was filled and pressed to the marked measurements in the inner wall of the column. Each soil layer was raked lightly before the next layer was packed to keep the continuity between the sub layers. All of the pots were regularly irrigated, and the water content was kept at 60% to 70% of the water holding capacity by adding water every 5 days to 6 days.

Sampling and analysis: Subsamples of biochar and the five kinds of soils used to determine the characteristics were collected from the samples filtered through the 2 mm, 1 mm and 0.25 mm sieves for laboratory analysis. After 4 months and 11 months of incubation, the soil sample sat the 0 cm to 10 cm and 10 cm to 20 cm layers were collected from 3 of the 6 replicates. After air-drying and collecting the litter, the soil samples were ground to pass through a1mmsieve to determine the soil pH levels.

The total carbon and nitrogen of the biochar was characterized by dry combustion with CHN element automatic analyzer (Yanaca CDRDER MT-3). Total ash content was determined using 800°C ignition in a muffle furnace for 2 h. Soil CEC of biochar and soil samples was determined with the NaOAc exchange and flame luminosity method described by Bao (2000). The pH levels of biochar and soil samples were measured using a 1:2.5 biochar/water suspension with a compound glass electrode (REX pHS-3C meter, China). Soil particle-size distribution of air-dried samples was measured through a laser diffraction technique using the Master Sizer-2000 (Malvern Instruments, Malvern, England). Soil organic carbon content was determined through the dichromate oxidation (external heat applied) method (Nelson & Sommers, 1982). Soil total nitrogen was analyzed according to the Kjeldahl digestion procedure (2300 Kjeltec analyzer unit, Foss Tecator, Sweden; Bremner & Tabatabai, 1972).

All samples and indices were analyzed in two replicates. The characteristics of the biochar and five soils used in the experiment are shown in Tables I and II, respectively.

Data analysis: All data in the research were recorded and classified using Microsoft Office Excel 2003. The different effects of biochar at different application rates and layers were examined by one-way analysis of variance (ANOVA).

Table I: Characteristics of the biochar

Parameter	Account
C (%)	66.67
H (%)	3.22
N (%)	2.21
pH (1:2.5H_2O)	8.38
CEC (cmolkg^{-1})	31.58
Ash (%)	12.50

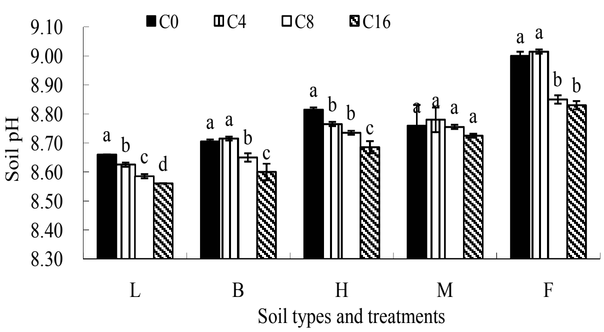
Table II: Physico-chemical characteristics of the soils

Parameter	L	B	H	M	F
Sand (%)	7.97	17.35	36.18	32.48	93.14
Silt (%)	78.90	68.85	57.70	61.76	6.74
Clay (%)	13.13	13.80	6.12	5.75	0.11
OC (g kg^{-1})	7.12	6.31	3.42	2.33	1.22
N(g kg^{-1})	0.76	0.69	0.42	0.30	0.12
pH (1:2.5H_2O)	8.66	8.71	8.82	8.76	9.00
CEC(cmol·kg^{-1})	22.4	13.95	8.60	8.05	3.42

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

Fig. 1: Initial soil pH condition after biochar mixed with soils

Treatment means and standard deviations in the same soil type followed by different letters are significantly different at $P < 0.05$. L: Lou soil; B: Dark Loessial soil; H: Loessal soil; M: Shahuang soil; F: Aeolian sandy soil



Duncan's multiple-range comparison test was used to compare means. Analyses of variance were carried out using SPSS16.0 statistical software.

RESULTS

Basic soil pH: Comparing the pH values of the biochar and five soil types used in the research (shown in Tables I & II, respectively), we found that the biochar used in this study had a pH value of 8.38, which is slightly lower than those of the five soils. The pH values of the L, B, H, M, and F soils ranged from 8.66 to 9.00 and were higher than that of the biochar by 0.28, 0.33, 0.44, 0.38 and 0.63 pH units, respectively.

Fig. 1 shows the pH values after mixing the biochar with the different soil types at different application rates. All pH values of the amended soils were influenced by the presence of biochar. Soil pH showed a tendency to decrease with increasing biochar application rate. Except the M soil, all of the other four soil types showed significant decrease in pH with the C_8 and C_{16} treatments. For the L and H soils, a significant decrease could be observed with the C_4 treatments. For all treatments of all soil types, the decrease rate was within 0.20 pH units. Comparing the C_{16} and C_0 treatments, the F soil demonstrated the largest decrease in pH at 0.17 pH units, while the smallest was shown by the M soil at 0.04 pH units.

Biochar contains carbonates and soluble base cations, such as calcium and magnesium (Van Zwieten *et al.*, 2010; Yuan *et al.*, 2011c). Except by dilution of the soil mixed with the low-pH biochar, the decrease in pH could be explained by the biochar cation content. The combination of the cations and the carbonate in the soil will form slightly soluble carbonates and restrict the hydrolyzation of carbonates, while decreasing the content of hydroxyl in the soil. Thus, the soil pH was decreased to some extent after the addition of biochar.

Soil pH after 4 months of incubation: Soil pH levels after 4months of incubation are shown in Table III. Except with the M soil, all C_0 treatments on the other four soils showed lower soil pH from the initial pH value. Thus, incubation for 4months decreased the soil pH slightly. Soil pH at the 0 cm to 10 cm layer was significantly higher than at the 10 cm to 20 cm layer in the C_0 treatments of the L, B and H soils. No significant difference was found in the C_0 treatment on the M and F soils, which showed higher soil pH level and lower soil organic carbon content above all other soil types.

At the 0 cm to 10 cm layer, higher biochar application rate in the L, B, and F soils resulted in lower soil pH. However, only the L soil type showed a significant pH decrease. The H soil demonstrated a non-significant increase in soil pH with the C_4, C_8 and C_{16} treatments. The M soild emonstrated a higher soil pH only with the C_4 treatment compared with the C_0 treatment with the same conditions when biochar was mixed with soil.

At the 10 cm to 20 cm soil layer, all the biochar treatments for the five soil types decreased the pH values of the soil. The L and M soil types demonstrated significant decreases in soil pH with the C_4, C_8 and C_{16} treatments with increasing biochar application rate. For the B and H soil types, the significant decrease was observed only with the C_{16} treatment. No significant decrease in pH was found in all the treatments on the F soil type.

Soil pH after 11 months of incubation: Soil pH levels after 11 months of incubation are given in Table IV. All the treatments of the five soil types produced higher soil pH than both the initial values and those obtained after 4 months of incubation. Significant differences between the 0 cm to 10 cm and 10 cm to 20 cm layers were found in all treatments in the study.

At the 0 cm to 10 cm layer, no significant difference was found in the treatments of the L, B, and H soil types, respectively. However, the C_4 treatment on B soil induced a significantly higher soil pH. For the M soil type, only the C_{16} treatment produced a significant decrease in soil pH. All the C_4, C_8 and C_{16} treatments of the F soil brought about a significantly lower soil pH than the C_0 treatment, andtheC_{16}treatment generated a decrease of 0.32 pH units.

At the 10 cm to 20 cm layer, all the treatments of the five soil types showed decreases in soil pH. However, no significant difference was found between the treatments on M soil and both C_8 and C_{16} treatments of the other four soil types have significant lower soil pH than the C_0 treatment. In addition, a significant decrease in soil pH was observed with the C_4 treatment on the B soil.

DISCUSSION

Soil pH change following incubation period: Comparing the soil pH variations across the five soil types at the initial stage and after 4 months and 11 months of incubation, the trend is generally a decrease in pH after 4 months of incubation and an increase after incubation for 11 months (Tables III & IV). The results obtained revealed the converse of the previously observed initial increase before the gradual decrease in soil pH during the addition of biochar into the acidic soils (Yuan *et al.*, 2011b). For the L, B, H and M soils, the pH at 11 months of incubation was much higher than at 4 months and a little higher than the initial values obtained. The F soil type showed the highest soil pH increase after 11 months of incubation, even higher than the initial condition.

All the control treatments of the five soil types demonstrated decreased soil pH after 4 months of incubation, which may be due to the acidic materials produced from the oxidation and decomposition of organic matter in the soil (Senesi & Plaza, 2007; Dias *et al.*, 2010). In addition, the low soil pH in the biochar treatments may be due to increased soil acidic material production. Biochar is not at all inert in soil and can be oxidized, especially at the surface, through chemical and microbial activity (Cheng *et al.*, 2006, 2008). The slow oxidization of biochar in soils can produce carboxylic functional groups (Brodowski *et al.*, 2005; Cheng *et al.*, 2006). Biochar in soils with organic matter applications will advance the oxidation of biochar (Novak *et al.*, 2010; Luo *et al.*, 2011). Meanwhile, the oxidation of organic matter in soil, which could also produce acidic matter, is also promoted by the presence of biochar (Liang *et al.*, 2010; Zavalloni *et al.*, 2011). The formation of the acidic functional groups can neutralize alkalinity and eventually decrease soil pH.

The increase of soil pH after 11 months of incubation emonstrated the salinization process. The supply of water brought chemical elements into the soil, whereas evaporation did not take the elements away. Since more frequent water treatments were done during the second incubation period, more elements were deposited in the soil. This eventually caused all the treatments to present higher soil pH. The decrease of soil pH with the biochar treatments showed a high soil buffering ability. In addition to the decrease due to acidic material production, biochar application would increase the soil CEC (Jones *et al.*, 2010; Laird *et al.*, 2010; Fellet *et al.*, 2011; Peng *et al.*, 2011; Yuan *et al.*, 2011b), which is an indicator of soil buffering capacity. Soil CEC may be increased with the application of biochar with high CEC. Moreover, the slow oxidization of biochar in soils can also increase soil CEC, thus enhancing the soil capacity to retain nutrients (Brodowski *et al.*, 2005; Cheng *et al.*, 2006). All of these mechanisms facilitate biochar restriction of the soil salinization process.

Table III: Soil pH of all treatments in the five soil types after 4 months of incubation

Soil types and layers	Treatments			
	C_0	C_4	C_8	C_{16}
L				
0 cm to 10 cm	8.55 ± 0.03a	8.52 ± 0.01b	8.47 ± 0.02c	8.48 ± 0.01c
10 cm to 20 cm	8.48 ± 0.02c	8.44 ± 0.03d	8.39 ± 0.01e	8.36 ± 0.02e
B				
0 cm to 10 cm	8.60 ± 0.01a	8.57 ± 0.05a	8.60 ± 0.00a	8.56 ± 0.03a
10 cm to 20 cm	8.49 ± 0.01b	8.46 ± 0.03b	8.45 ± 0.02b	8.40 ± 0.02c
H				
0 cm to 10 cm	8.69 ± 0.02a	8.72 ± 0.03a	8.73 ± 0.03a	8.72 ± 0.02a
10 cm to 20 cm	8.61 ± 0.06b	8.61 ± 0.01b	8.59 ± 0.02bc	8.54 ± 0.01c
M				
0 cm to 10 cm	8.71 ± 0.02b	8.77 ± 0.02a	8.71 ± 0.03b	8.73 ± 0.02b
10 cm to 20 cm	8.70 ± 0.02b	8.64 ± 0.02c	8.55 ± 0.01d	8.54 ± 0.03d
F				
0 cm to 10 cm	8.87 ± 0.05a	8.87 ± 0.06a	8.78 ± 0.05ab	8.78 ± 0.05ab
10 cm to 20 cm	8.79 ± 0.04ab	8.72 ± 0.02b	8.71 ± 0.03b	8.72 ± 0.08b

Treatment means and standard deviations in the same soil type followed by different letters are significantly different at $P < 0.05$. L: Lou soil; B: Dark loessial soil; H: Loessal soil; M: Shahuang soil; F: Aeolian sandy soil

Table IV: Soil pH of all treatments in the five soil types after 11 months of incubation

Soil types and layers	Treatments			
	C_0	C_4	C_8	C_{16}
L				
0 cm to 10 cm	8.79 ± 0.03a	8.85 ± 0.02a	8.83 ± 0.03a	8.82 ± 0.04a
10 cm to 20 cm	8.52 ± 0.02b	8.49 ± 0.02b	8.42 ± 0.07c	8.37 ± 0.01c
B				
0 cm to 10 cm	8.79 ± 0.02b	8.83 ± 0.03a	8.80 ± 0.01ab	8.80 ± 0.02ab
10 cm to 20 cm	8.46 ± 0.04c	8.43 ± 0.02d	8.42 ± 0.00d	8.41 ± 0.02d
H				
0 cm to 10cm	8.86 ± 0.04ab	8.89 ± 0.02a	8.90 ± 0.04a	8.83 ± 0.03b
10 cm to 20 cm	8.70 ± 0.03c	8.70 ± 0.02c	8.65 ± 0.02d	8.62 ± 0.03d
M				
0 cm to 10 cm	9.01 ± 0.10 ab	9.07 ± 0.04 a	8.97 ± 0.07bc	8.91 ± 0.02 c
10 cm to 20 cm	8.77 ± 0.05d	8.74 ± 0.03d	8.74 ± 0.09d	8.72 ± 0.01d
F				
0 cm to 10 cm	9.51 ± 0.08a	9.38 ± 0.09b	9.28 ± 0.01c	9.19 ± 0.01d
10 cm to 20 cm	8.98 ± 0.02e	8.95 ± 0.05e	8.85 ± 0.03f	8.81 ± 0.02f

Treatment means and standard deviations in the same soil type followed by different letters are significantly different at $P < 0.05$. L: Lou soil; B: Dark loessial soil; H: Loessal soil; M: Shahuang soil; F: Aeolian sandy soil

Effect of biochar on soil pH at different soil layers: Differences in the pH values between the 0 cm to 10 cm and 10 cm to 20 cm layers could be observed both during 4 months and 11 months of incubation periods. The upper layer was always observed to register higher soil pH. Except the C_0 treatment at 4 months of incubation, the differences

Table V: Differences in pH between the 0 cm to 10 cm and 10 cm to 20 cm layers in all treatments on the five soil types

	C_0	C_4	C_8	C_{16}
L				
4 months	0.07 ± 0.03a	0.07 ± 0.04a	0.08 ± 0.02a	0.12 ± 0.02a
11 months	0.27 ± 0.05c	0.36 ± 0.02b	0.41 ± 0.05ab	0.45 ± 0.05a
B				
4 months	0.11 ± 0.01b	0.10 ± 0.04ab	0.15 ± 0.02ab	0.16 ± 0.03a
11 months	0.33 ± 0.04b	0.40 ± 0.02a	0.38 ± 0.01a	0.39 ± 0.02a
H				
4 months	0.07 ± 0.08b	0.12 ± 0.03ab	0.14 ± 0.04ab	0.18 ± 0.03a
11 months	0.16 ± 0.06b	0.19 ± 0.01ab	0.24 ± 0.06a	0.21 ± 0.03ab
M				
4 months	0.02 ± 0.02c	0.12 ± 0.02b	0.16 ± 0.04ab	0.18 ± 0.02a
11 months	0.24 ± 0.07a	0.33 ± 0.03a	0.23 ± 0.15a	0.19 ± 0.03a
F				
4 months	0.07 ± 0.05a	0.14 ± 0.07a	0.06 ± 0.04a	0.06 ± 0.06a
11 months	0.53 ± 0.09a	0.43 ± 0.13a	0.44 ± 0.04a	0.38 ± 0.03a

Treatment means and standard deviations within a row followed by different letters are significantly different at $P < 0.05$. L: Lou soil; B: Dark loessial soil; H: Loessal soil; M: Shahuang soil; F: Aeolian sandy soil

were all significant. Therefore, most of the alkaline material deposited from the addition of water was concentrated at the surface of the biochar treatment. This result was in accord with previous research results describing the capacity of biochar to store chemical elements and decrease the leaching of the cations (Laird *et al*., 2010).

The differences in soil pH between the two layers widened with increasing incubation duration (Table V). The result could also be ascribed to the salinization process that the irrigation and evaporation brought about with the elements deposited on to the surface layer, thereby increasing soil alkalinity (Saysel & Barlas, 2001).

Biochar application has produced an increasing trend in the difference between the 0 cm to 10 cm and 10 cm to 20 cm layers (Table V). Except with the F soil type, all the other biochar treatments produced a widening difference between the two layers with increased application rates. The sorption due to biochar and the salinization process brought about by water evaporation jointly created the effect. Thus, the biochar treatments induced lower soil pH at the 10 cm to 20 cm layer compared with the control.

Soil pH at the 0 cm to 10 cm layer did not show a significant difference with the control treatment in the L, B, and H soils after 11 months of incubation. The acidic functional groups produced from the oxidation of biochar and organic matter in the soils may have off set some alkalinity, which accounts for the sustained soil pH at the surface layerin relation to control values (Tables III & IV).

For the F and M soils, decreased soil pH at the 0 cm to 10 cm layer was observed with the biochar treatments. The C_{16} treatment on the M soil and all the treatments on the F soil significantly lowered the soil pH compared with control. Biochar application might favorably improve the soil CEC in soil with low CEC value (Van Zwieten *et al.*, 2010). The better improvement of soil CEC on the F and M soils, which have low soil CEC, during biochar application would restrict soil pH increase through increased soil buffering ability.

Effect of biochar on different soil pH: From Table II, we can rank the soil types accordingly as the L and B soil to silt loam soil, H and M soils to sandy loam soil and F soil to sandy soil. Furthermore, the content of fertility indices, such as OC, N, and CEC, followed the order L > B > H > M > F (Table II). The different effects of biochar on the five soil types are due to different soil compositions and fertility levels under alkaline conditions.

Biochar application has different effects on the five soil types. However, the effects cannot be distinguished according to the different soil classes. For the L soil, which has the highest fertility content, the decrease in soil pH was more evident in the short incubation period, and the upper and lower soil layers showed the same significantly decreasing trend. For the other silt loam soil, B soil, the decrease was only observed at the 10 cm to 20 cm layer. However, with increasing incubation duration, the C_4 and C_8 treatments produced a significant pH decrease (Table IV). Only the C_{16} treatment decreased the soil pH in all incubation periods for the H soil type. With the increase of the incubation period and soil pH, the differences among the treatments on M soil were only observed at the 0 cm to 10 cm layer. The F soil became the most alkaline soil type after 11 months of incubation, but the significant decrease in soil pH was found at both the 0 cm to 10 cm and 10 cm to 20 cm layers. Thus, biochar application is demonstrated as an amendment to restrict soil pH increase for sandy soil.

Based on the results, soils with high organic carbon content (such as L soil) will have a significant decrease in soil pH during short-term incubation due to the oxidation and decomposition of soil organic matter and the biochar itself, especially at the surface layer. On the other hand, soils with low organic carbon content (like F soil) will be significantly limited on soil salinization due to the increased soil CEC produced by biochar application.

In conclusion, the results of the research eliminated the concerns regarding the application of biochar, an alkaline organic material, increasing the soil pH of alkaline soils. On the contrary, the application of biochar with lower pH than the targeted soils might have the potential to decrease soil pH in all of the five different alkaline soil types in the Loess Plateau, especially at a high application rate. The dilution of the cations in the biochar may decrease soil pH at the initial phase when biochar is mixed with soils. However, the increased soil CEC caused by biochar may increase soil buffering ability during the incubation process. In addition, the eventual oxidation and decomposition of biochar and organic matter in the soils can form the acidic materials that will partly neutralize soil alkalinity, which makes biochar a limiting agent of the soil salinization process. The results of the research should be further tested in field experiments using different kinds of biochar and plant growth conditions.

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