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Effects of Flax Straw Biochar on Soil Properties, Fractions and Maize Availability of Lead and Cadmium in Light Sierozem

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ABSTRACT

Bioavailability of heavy metals can be reduced in acidic soils with biochar amendment but the situation in alkaline soils is not much clear. Effects of four rates (1%, 5%, 10% and 15% w/w) of flax (*Linum usitatissimum* L.) straw biochar (FBC) prepared at 600°C on the properties of soil, fraction and phytoavailability of Pb and Cd, and plant growth in the simulated Pb (1000 mg.kg^{-1}) or Cd (20 mg.kg^{-1}) contaminated light sierozem were assessed with pot experiments using maize (*Zea mays* L.) as an indicator plant. The amendment of FBC significantly enhanced the pH value, cationic exchange capacity (CEC) and organic matter of soil ($P < 0.05$). The BCR sequential extraction results indicated that the acid extractable fraction of Pb or Cd only decreased by 12.80% or 5.56% when FBC was added with the high rate of 15%. The uptake of Pb or Cd by maize shoots scarcely decreased with 1% and 5% of FBC amendment. Significant inhibitory effects of FBC on the growth of maize shoots were observed with FBC amendment at the rates of 10% and 15%. The results could provide a different implication for immobilization remediation of loess soils (e.g., light sierozem) contaminated with heavy metals.

INTRODUCTION

The loess soils are extensively spreading in the world, which covers the one-tenth of the global land area, especially in the northwestern region of China and central Asia. In general, loess soil has loose structure, large porosity and water permeability, low agglomerating force and organic matters (Zhu et al. 1983). Moreover, due to the irrigation using industrial wastewater, unwarrantable disposal of solid wastes (e.g., sludge, garbage, etc.), application of agrochemicals and fertilizers, and atmospheric deposition, serious contamination by heavy metals in loess farmlands occur (Liu et al. 2010, Zhao & Wang 2010). Of heavy metals produced through anthropogenic activities in the area, Pb and Cd are considered the most harmful for human health and accumulate at high rates in soils. For example, the discharge of contaminants containing Pb from a few of lead and zinc smelting plants resulted in the fearful contamination of soil and the high level of Pb in children's blood in Huixian, a county town in the northwestern China, in 2006 (Ding 2006). Currently, the concentrations of Cd in the farmlands around Baiyin city, which is the largest nonferrous metal base in northwestern China, even exceed the average one in Toyama County, Japan, where 'Itai Itai' disease was caused at that time (Zhao & Wang 2010). Therefore, improvement and remediation of loess soils are of utmost importance and urgency. It has been proved that the application of soil amendments that bind or precipitate contaminants whilst promoting plant growth can reduce environmental risk (Beesley & Marmiroli 2011, Bolan et al. 2014, Uchimiya et al. 2010, Yang et al. 2017).

Biochar is a carbon-rich by-product derived from the pyrolysis of biomass under oxygen limited condition and has been suggested to be an innovative and promising method to mitigate climate change (Lehmann 2007a), improve soil properties and enhance crop yields (Lehmann & Joseph 2009). Moreover, biochar could be an *in-situ* immobilization alternative to remediate soils contaminated with heavy metals due to its capability to enhance pH value of soil, resulting in precipitation of heavy metals, and to adsorb heavy metals, originating from its porous structure, negatively charged surface and large number of functional groups on the surface (Lehmann & Joseph 2009, Ladygina & Rinceau 2013). Therefore, it seems that biochar should be applied to loess soil to improve soil properties and enhance crop yield, to remediate the contamination by heavy metals, and ensure food safety.

A few researches on remediation of soils contaminated with Pb and Cd using amendment of biochars were conducted but most of them aimed at acidic soils (Bian et al. 2013, Bian et al. 2014, Houben et al. 2013, Jin et al. 2011, Li et al. 2016, Lu et al. 2014, Mohamed et al. 2015, Niu et al. 2015). From the results, it has been shown that amendment of biochar significantly increased soil pH value, electrical conductivity (EC), organic matters (OM), and cationic exchange capacity (CEC), etc. Meanwhile, application of biochar significantly reduced extractable Pb and Cd concentrations in soils and was effective in metal immobilization, thereby reducing the bioavailability and phytotoxicity of Pb and Cd and enhancing crop growth. Even a low rate amendment of biochar could lead to positive effectiveness for soil properties, bioavailability of heavy metals and yield of crops. These results also indicate that change of soil properties, especially pH value, could be a good reason to illustrate the immobilization of Pb and Cd in the biochar treated soils. However, the properties of alkaline soils such as loess soils are very different from those of acidic ones due to their high pH values, high contents of carbonates and low contents of organic matters. Thus, the effect of a biochar on loess soil could quite differ from that on acidic one. Up to date, there are few references (Al-Wabel et al. 2015, Khanmohammadi et al. 2016, Zhao et al. 2016) reporting the effects of biochars on soil properties, bioavailability of heavy metals and plant growth in loess soils (e.g. light sierozem), to our knowledge.

One of the main crops, flax (*Linum usitatissimum* L.) is widely cultivated in the northwestern region of China. As the usual burning disposal of crop wastes in farmland in China, most of the flax straw residuals are also not adequately disposed and utilized. A reasonable utilization of flax residuals is expected. Therefore, in this paper, flax straw was used as a precursor to prepare biochar at 600°C (FBC). The effects of FBC amendment on the soil properties, fraction and phytoavailability of Pb and Cd, and maize growth in simulated contaminated light sierozem were tested and evaluated using a pot incubation experiment.

MATERIALS AND METHODS

Chemicals and materials: $Pb(NO_3)_2$ and $Cd(NO_3)_2$) with analytical grade were purchased from Shanghai Chemical Co., China. Deionized water was used in all the experiments.

The sandy loam soil (0-20 cm) was sampled at a hill in Lanzhou Jiaotong University, China, which was classified as light sierozem (Zhu et al. 1983). The soil sample was thoroughly mixed, air-dried and passed through a 2 mm sieve. The basic properties of soil, such as pH value, concentration of background Pb or Cd, CEC value, content of organic matter (OM), content of carbonates and soil texture were determined using the methods as reported previously and listed in Table 1 (Zhao et al. 2016).

Flax straw was collected from a farmland around Lanzhou City, China. The pretreatment of biomass and the preparation of biochar were similar to those reported previously (Zhao et al. 2016). Flax straw was cleaned with tap water, dried at 80°C for 12 h in a drier (Beijing Kewei Yongxing Instrument Co., China), and ground using a grinder. The debris was passed through a 0.43 mm sieve and placed into a crucible. Then, the samples were placed in a muffle furnace at 600°C for 4 h to pyrolyze the biomass. The obtained biochar was referred to as FBC. The values of pH, CEC, OM and carbonate of FBC were determined using the same methods as those for soil sample. The ash content, element fractions and specific surface area were tested using the methods described by Zhao et al. (2016). The basic properties of FBC are also listed in Table 1.

Pot experiment: The natural soil was spiked using $Pb(NO_3)_2$ or $Cd(NO_3)_2$ solution, with the final concentration of Pb(II) as 1000 $mg.kg^{-1}$ or that of Cd(II) as 20 $mg.kg^{-1}$. The spiked soils were placed in the dark for 1 month and kept with 70% of the field water holding capacity. Then they were air-dried and passed through 2 mm sieve. One kg of the Pb or Cd-contaminated soil was thoroughly mixed with 5 g of a slow-releasing fertilizer ($N : P_2O_5 : K_2O = 15 : 15 : 15$) and FBC with 1%, 5%, 10% and 15% rates, respectively. The mixed soil was padded into a pot with 130 mm × 116 mm scale. The sample with no FBC addition was prepared as blank control (CK). Three replicates per treatment were prepared.

The incubation experiments similar to those reported previously were conducted (Zhao et al. 2016), keeping 25°C of temperature, 40% of average humidity and 16 $h.d^{-1}$ of light. Two months later, 6 of maize seeds (*Zea mays* L.,

Table 1: Basic properties of soil and biochar.

	Soil	FBC
pH	8.23	10.03
CEC ($cmol·kg^{-1}$)	5.10	22.7
OM ($g·kg^{-1}$)	9.20	296.58
Carbonate ($mg.kg^{-1}$)	117.32	59.84
BET specific area ($m^2.g^{-1}$)	8.0321	14.99
Cd ($mg.kg^{-1}$)	0.34	
Pb ($mg.kg^{-1}$)	23.64	
Soil texture (%)	Grave 12, Silt 62.40, Clay 25.60	
Ash content (%)	-	15.39
Element analysis (%)	-	C 66.02, H 1.82, N 0.21, S 0.31, O 16.25

Longyuan No. 3, obtained from Beijing Kenfeng Longyuan Seed Technology Co. Ltd., China) were sowed in each pot. After germination for 1 week, three seedlings were retained. After the plants grew for one month, they were harvested and the soil samples were collected. The harvested plants were washed, determined the height and oven-dried in paper bag at 70°C. Then the plant samples were ground and stored for further analysis. The soil from each pot was air-dried, mixed and passed through a 2 mm sieve. The values of soil pH, CEC, OM, carbonate and concentration of Pb or Cd in soil were analysed using the same methods as mentioned above for the soil. The fractions of Pb and Cd in soils were determined using the modified BCR method (Zhang et al. 2012). The content of Pb and Cd in plant sample was determined using HNO_3-HF-$HClO_4$ digestion (Lambrechts et al. 2011) and AAS method.

Data analysis: The statistical analysis was carried out using SPSS 21.0. The mean and standard deviation were obtained using single factor variance analysis method. The significant difference analysis was done using the new Duncan's multiple range test ($P < 0.05$). In the present study, the different letters were used to indicate significant difference among the values from treatments.

The coefficient of binding strength between a heavy metal and soil (Han et al. 2003), I_R, is defined as:

$$I_R = \sum_{i=1}^{4} (F_i \times i^2)/16 \qquad ...(1)$$

Where, F represents the mass fraction of heavy metal; i (= 1, 2, 3 and 4) represents the number of heavy metal speciation, based on BCR continuous extraction method.

RESULTS AND DISCUSSION

Change of soil properties: Data in Table 2 show the change of basic chemical properties (pH, CEC, OM and carbonate content) of soil after the application of FBC in the Pb or Cd-contaminated soil at the rates of 1%, 5%, 10% and 15%.

The pH values of soils increased significantly ($P < 0.05$) with FBC application. The highest soil pH 8.86 and 8.90 corresponding to the 15% FBC treatments in Pb and Cd-contaminated soil are about 0.8 pH unit larger than those of the CK treatments, respectively. This is similar to the result by Al-Wabel et al. (2015), which indicated *Conocarpus* biochar (pH = 9.85) increased the pH value 7.98 of an alkaline soil up to 8.15 when the biochar application rate was 5%. Light sierozem belongs to the calcareous soils, with a relatively high background pH value due to its large content of carbonates (Zhu et al. 1983). This kind of soil is less capable to buffer the basic materials. Meanwhile, FBC had a much higher pH value (10.03) than that of soil (8.23) and contained quite a few basic materials (mainly present in the ash) (Table 1). Therefore, the pH values of the contaminated soils were extraordinary high after the amendment of FBC at the high rates (10% and 15%). It has been reported that an increase in soil pH would promote heavy metal adsorption and precipitation, thereby reducing their bioavailability (Zhang et al. 2013b). However, much higher pH soil is not apt for crop growth.

According to the results from the previous studies, the acidic soil pH also increased significantly with biochar application (Bian et al. 2014, Li et al. 2016, Lu et al. 2014, Mohamed et al. 2015, Niu et al. 2015, Zhang et al. 2013b). In addition, cationic metal adsorption to biochar could be much enhanced because more negative charges occurred on biochar surface with pH improvement (Beesley & Marmiroli 2011). However, it should be pointed out that the ultimate pH values of acidic soils after application of biochars even with high rates were not so high as the intrinsic pH of the soil in the present study (Bian et al. 2014, Houben et al. 2013, Jin et al. 2011, Li et al. 2016, Lu et al. 2014, Mohamed et al. 2015, Niu et al. 2015). For example, 5% amendment of a rice straw biochar, which was obtained at 500°C with a pH value of 10.0 increased significantly ($P < 0.05$) the pH value 5.7 of a sandy loam paddy soil contaminated with Cu, Cd, Pb and Zn up to about 6.1-6.2 (Lu et al. 2014). The ultimate soil pH values would affect speciation, adsorption and immobilization of heavy metals, and plant growth. Although the biochar amendment resulted in pH increase of both acidic and basic soils, the results would be much different. Thus, the effect of a biochar on bioavailabilty of heavy metals in basic soils (e.g., loess) would be different from that in acidic soils.

Table 2 shows that FBC increased the values of CEC of the contaminated soils. Generally, it is admitted that the effect of biochar addition on CEC in acidic soils is dependent on the type of biomass (Jha et al. 2010) and pyrolysis temperature (Lehmann 2007b). The acidic functional groups on biochar can react with the hydroxylated surface of metal oxides, improving the value of soil CEC (Prendergast-Miller et al. 2014). The soil CEC improvement by FBC application could be partially attributed to the physical mixing of FBC with a relative high CEC into the light sierozem with a low CEC. In addition, the increase of soil pH might promote the dissociation of surface hydroxyl on the soil colloidal particles, so the negative charges on soil surface and the CEC of soil increased accordingly. Being similar to the effects of biochars on OM of acidic soils contaminated with Pb and Cd (Bian et al. 2014, Mohamed et al. 2015), the amendment of FBC also increased significantly ($P < 0.05$) the values of OM in the contaminated soils (Table 2). It can be believed that the increment will be much obvious when

Table 2: Effects of FBC amendment on soil properties.

Soil properties		Application rate of FBC (%)				
		0	1	5	10	15
Pb	pH	8.01±0.06e	8.13±0.03d	8.35±0.03c	8.57±0.04b	8.86±0.06a
	CEC (cmol.kg^{-1})	5.51±0.43d	6.18±0.18c	6.71±0.35c	7.41±0.34b	9.28±0.27a
	OM (g.kg^{-1})	12.28±2.58e	26.66±5.38d	77.61±3.07c	142.53±4.89b	184.54±9.94a
	Carbonate (mg.kg^{-1})	132.19±1.99a	123.73±1.62ab	121.47±2.57b	111.13±8.72c	101.46±7.76c
Cd	pH	8.06±0.02e	8.11±0.01d	8.43±0.02c	8.62±0.06b	8.9±0.05a
	CEC (cmol.kg^{-1})	6.05±0.07e	6.78±0.23d	7.53±0.08c	8.01±0.14b	9.02±0.24a
	OM (g.kg^{-1})	11.37±2.57e	23.29±4.36d	73.35±6.44c	134.39±8.79b	196.72±9.38a
	Carbonate (mg.kg^{-1})	125.33±2.73b	126.27±3.95b	123.34±5.97	121.32±4.02b	116.57±7.02a

Table 3: Change in height (cm) of maize shoots with amendment rate of FBC.

Soil	Application amount of FBC (%)				
	0	1	5	10	15
Pb	30.25±3.49a	30.48±2.89a	28.34±2.62ab	21.87±5.36b	10.58±3.53c
Cd	33.50±2.56a	30.45±1.80a	31.51±2.87a	14.32±3.01b	9.22±2.08c

a soil with low organic matter (i.e., light sierozem) is tested. When the amount of FBC is 15%, the OM in the Pb and Cd-contaminated light sierozems was 15 times and 17 times as that in the CK treatments, respectively. In Table 2, it is also shown that the contents of carbonates did not exhibit significant change with the addition of FBC, mainly due to the intrinsic high carbonate content in light sierozem.

Fraction distribution of Pb and Cd: By the method of BCR, the fractions of Pb and Cd in the soils were divided into four forms, that is, acid extractable (ACI), Fe-Mn oxide bound (FEM), organic matter bound (ORG) and residual one (RES), of which ACI is considered to be more bioavailable. The distribution of different fractions of Pb and Cd in the contaminated soils after FBC addition is shown in Fig. 1.

As shown in Fig. 1, the contents of fractions of Pb were in the order of ACI > FEM > ORG > RES, indicating that Pb existed mainly in the form of ACI. As the amount of FBC application increased, the percentage content of ACI decreased significantly, that of FEM decreased slightly, that of ORG increased slightly and that of RES increased obviously. Compared with the corresponding fraction contents of Pb in the CK treatment, those of ACI and FEM fractions decreased only by 12.8% and 5.13%, and those of ORG and RES ones increased only by 6.01% and 12.02%, respectively, when FBC was applied at the rate of 15%. The contents of fractions of Cd were also in the order of ACI > FEM > ORG > RES. However, the ACI contents of Cd were 64.8%, 64.57%, 63.93%, 61.65% and 59.24% when FBC was added at the 0%, 1%, 5%, 10% and 15% rates, being much larger than those of the other fractions. 15% of FBC amendment decreased the ACI content of Cd only by 5.56%.

Although different extraction methods were used to evaluate the effects of biochars on the bioavailability of heavy metals in acidic soils, compared with the results in the previous studies (Bian et al. 2014, Houben et al. 2013, Li et al. 2016, Lu et al. 2014, Mohamed et al. 2015, Niu et al. 2015), the decreases in available fractions of Pb and Cd by BCR method, especially Cd, were not so obvious in the present study. For example, the concentration of extractable Pb in paddy soils amended with fine and coarse rice straw biochar at a dose of 5% significantly ($P < 0.05$) decreased, which was 4.4 and 6.3 mg.kg^{-1}, respectively (Lu et al. 2014). Beesley et al. (2010) reported that a hardwood-derived biochar amendment (8.3%, w/w) significantly reduced water-extractable Cd concentration in soil. Cao et al. (2011) showed that dairy manure biochar could immobilize Pb in soil via both adsorption and precipitation, thereby leading to the transformation from less stable Pb species to more stable hydroxyl pyromorphite. The less decrease of ACI Pb and Cd by FBC addition in this study could be attributed to the main metal species in loess. It has been reported that the sorbed species of Pb(II) and Cd(II) on loess were mainly $Pb(CO_3)_2$ and $Cd(OH)_2$ precipitation with the pH values of solutions ranging between 8 and 9, respectively (Liu 2014, Wang 2012). That is to say, $Pb(CO_3)_2$ and $Cd(OH)_2$ could be the main contents in the ACI fractions of Pb and Cd by BCR method, respectively. Thus, the added FBC could not decrease the main portion of precipitation in ACI fractions of Pb and Cd in the soils while could decrease the small portion such as soluble or exchangeable metal species in the fraction of ACI.

Comparing the fraction distributions of Pb and Cd in

Fig. 1, it can be found that the ACI percentages of Pb were significantly less than those of Cd. It is likely that the strength of Pb binding to the soil matrix was stronger than that of Cd. Fig. 2 shows the plots of the coefficients of binding strength between Pb or Cd and soil (I_R) versus the amendment rates of FBC. If the heavy metal fraction in soil was only ACI one, the I_R value would be the minimum, with a value of 0.0625; if the heavy metal fraction in soil was only RES one, the I_R value would be the maximum, with a value of 1 (Han et al. 2003). Thus, low I_R values indicate that Pb and Cd mainly existed in extractable and unstable state, and high ones show that Pb and Cd mainly existed in stable forms. The value of I_R in the Pb-contaminated soil increased significantly ($P < 0.05$) by 60% with the application of FBC being at 15%. However, that in the Cd-contaminated soil increased slightly with FBC amendment.

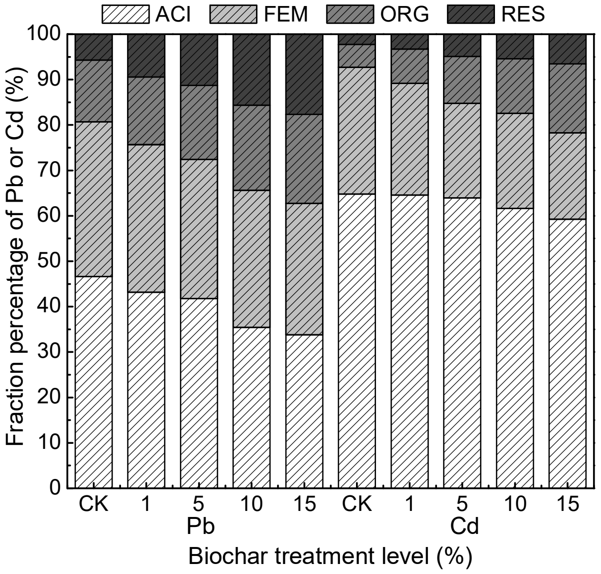

Fig. 1: Distribution of different fractions of Pb and Cd in soils versus FBC addition.

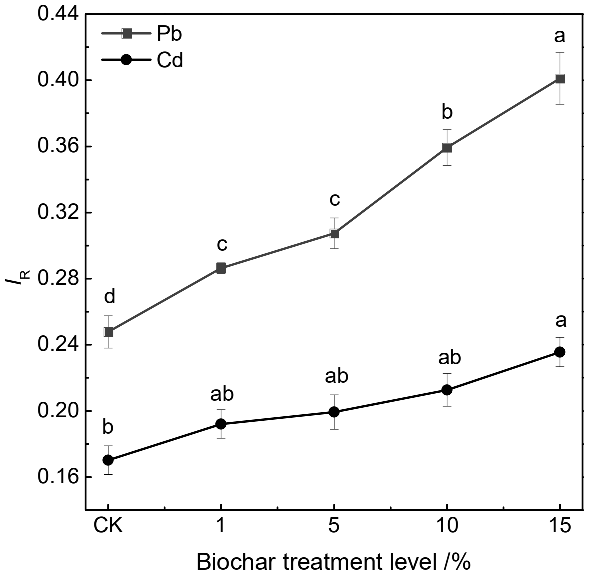

Fig. 2: Plots of IR values of Pb and Cd versus amendment rates of FBC.

Growth of maize: It is shown in Table 3 that there was no significant change in the height of maize shoots with the low rates 1% and 5% of FBC into the Pb and Cd-contaminated soils. However, there was much significant decrease in the height of maize shoots when the rates of FBC were used as 10% and 15%. The heights of maize shoots in the 15% FBC treatments were only 35.0% and 27.5% as those in the CK treatments for Pb and Cd-contaminated soils, respectively. It seems that the values of the soil pH exceeded the suitable range for plant, which inhibited the growth of maize shoots, and the maize heights were significantly decreased.

It has shown that biochar application could significantly increase in plant biomass or crop yield into acidic soils, even though at its low rate of amendment. Lu et al. (2014) found that the biomass of *S. plumbizincicola* was significantly ($P < 0.05$) increased in the Cd, Cu, Pb and Zn co-contaminated paddy soil (pH = 5.7) with 1% and 5% of rice straw and bamboo biochars. Niu et al. (2015) found that treatment with slash-and-char increased the productivity of *Brassica parachinensis*, *Brassica chinensis*, *Brassica juncea* var. *crispifolia* and *Brassica oleracea* var. *oleracea* by 34-67%, which were planted in the Cd, Pb and Zn contaminated soils. It has been found by Mohamed et al. (2015) that the increase of bamboo residue biochar rates from 0% to 1.5% enhanced the growth of cabbage by 64.23%, 47.31% and 34.93%, and maize by 50.78%, 32.83% and 29.68% in soils treated with Cd at 0, 5 and 50 mg.kg^{-1}, respectively. Biochars' liming value would help enhance soil pH when applied to acidic soils (Beesley & Marmiroli 2011). The increase in productivity of crops (maize, soybean and radish) might originate from the increased soil pH due to biochar addition in an acidic soil (Chan et al. 2008). Biochar amendment into contaminated soils could reduce metal toxicity to plants and metal uptake by plant and increased growth of plant (Park et al. 2011, Zhang et al. 2013a). However, the situation in the present study was very different.

Plant uptake of Pb and Cd: Fig. 3 shows the contents of Pb and Cd in the roots, stems, leaves and plants of maize shoots change with the different treatment level of FBC. It can be seen that the extent of Pb accumulation in the different parts of maize shoots was in the order of roots > stems > leaves. The patterns of Pb contents in roots and plants changing with FBC application were similar, which decreased significantly

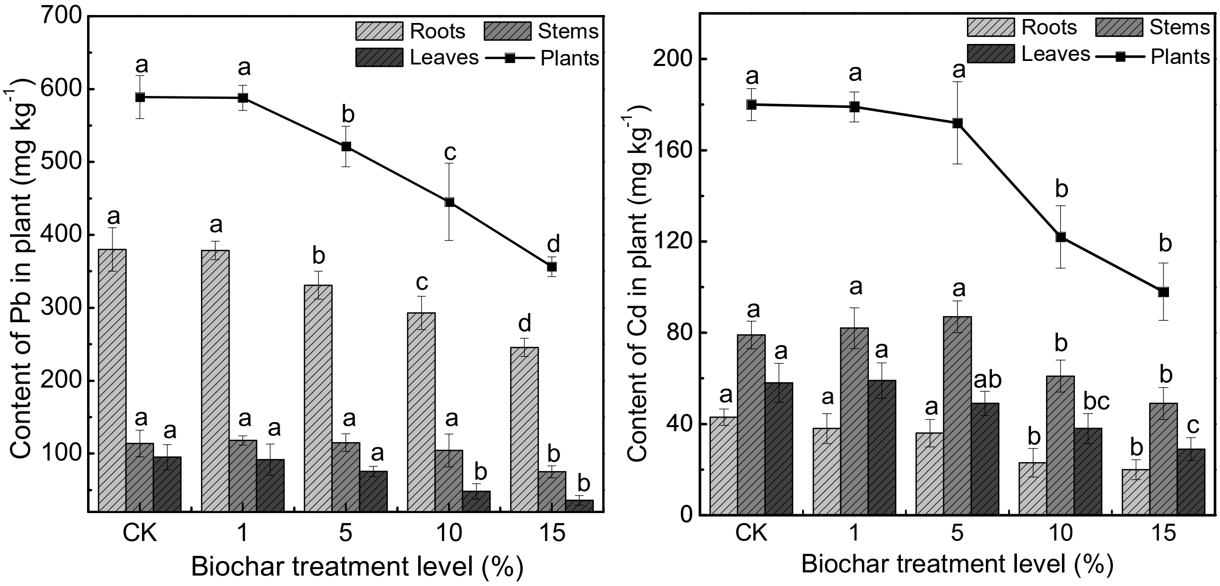

Fig. 3: Contents of Pb and Cd in maize shoots versus amendment rates of FBC.

($P < 0.05$) when FBC was applied in the amount of 5%, 10% and 15%. However, only the content of Pb in stems in the 15% FBC treatment was significantly ($P < 0.05$) different from that in the CK treatment while the contents of Pb in leaves in the 10% and 15% FBC treatments were significantly ($P < 0.05$) different from those in the corresponding CK treatments. Cd accumulation in the different parts of maize shoots was in the order of stems > leaves > roots. The change trends of Cd accumulation in roots, stems, leaves and plants were similar with the 5%, 10% and 15% addition of FBC. The contents of Cd in roots, stems, leaves and plants in the 10% and 15% FBC treatments were significantly ($P < 0.05$) different from those in the corresponding CK treatments. The content of Pb (or Cd) in plants scarcely decreased with 1% and 5% of FBC amendment. It seems that high rates of FBC application could significantly decrease the phytoavailability of Pb and Cd to maize shoots in light sierozem. For example, the contents of heavy metals in the plants greatly decreased by 24.4% (Pb) and 39.5% (Pb), and 32.2% (Cd) and 45.6% (Cd) when large amount (10% and 15%) of FBC were applied respectively. However, it should be pointed out that this decrease heavy metals in plants was accompanied with the significant decreases of biomass of plants.

Much decrease in uptake of Pb and Cd in plants in acidic soils was reported using low rate of biochar application (Bian et al. 2014, Lu et al. 2014, Mohamed et al. 2015, Niu et al. 2015, Li et al. 2016). The concentration of Cd in shoots of *S. plumbizincicola* significantly ($P < 0.05$) decreased with both 5% of bamboo and rice straw biochar application by up to 49% and 20%, respectively (Lu et al. 2014). The application of corn straw biochar at 5% resulted in 38.8% decrease in Cd content in the polished grain of rice compared to that of the control (Li et al. 2016). The concentrations of Pb and Cd were significantly ($P < 0.05$) reduced in vegetables growing in the biochar treated soil compared to those in the untreated soil (Niu et al. 2015). Concentration of Cd in shoots and roots of cabbage and maize plants significantly decreased with bamboo biochar addition (Mohamed et al. 2015). Cd concentration in the rice grain decreased significantly over the three years, depending on the wheat straw biochar application rates (Bian et al. 2014). Similarly, chicken manure-derived biochar significantly reduced the uptake of Cu and Pb by *Brassica juncea* L. (Park et al. 2011). Wheat chaff-derived biochar at an application rate of 5% significantly ($P < 0.05$) reduced the Cd concentration of *J. subsecundus* N.A. Wakef (Zhang et al. 2013*a*). Biochar reduced the uptake of Cu and Pb by ryegrass (Karami et al. 2011) and 5% straw biochar additions caused the greatest decrease in Cu and Pb concentrations in rice shoots (Zheng et al. 2012). However, no inhibitory but enhancing effect on plant growth was observed when the given low amounts of biochars were applied in these studies.

In general, the decrease of heavy metals in plant has been believed to be mainly attributed to the decrease of bioavailable fraction content of heavy metals in soils. The decrease in Cd concentration in plants in the presence of biochar application may be attributed to both the immobilization of bioavailable metals and 'dilution effect' due to increased plant biomass (Park et al. 2011). Cu availability in the biochar treatments may be reduced due to sorption, complexation and precipitation (Beesley et al. 2010, Zhang et al. 2013b). However, in the present study, the ACI fraction of Pb or Cd only decreased by 12.80% or 5.56% when FBC was added with the high rate 15%. The significant enhanced soil pH value might inhibit maize growth, resulting in the difference of the plant metabolism and different uptake of Pb and Cd by maize shoots.

CONCLUSIONS

This study presented evidence to illustrate the effects of flax straw biochar on the properties of soil, fraction and maize availability of Pb and Cd, and maize growth in Pb or Cd-contaminated light sierozem. Although the amendment of FBC significantly enhanced the values of soil pH, the acid extractable fractions of Pb and Cd did not largely decrease with the amendment of FBC. Low rates of FBC addition into the soils exhibited no significant effect on maize growth and uptake of Pb and Cd in maize shoots. It seems that high rates of FBC addition led to the decrease in uptake of Pb and Cd but its inhibitory effect on maize growth occurred obviously. Our findings might supply a different implication for immobilization remediation of alkaline soils (e.g., light sierozem) contaminated with heavy metals, such as Pb and Cd.

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