Environ Earth Sci (2016) 75:630
DOI 10.1007/s12665-016-5440-9

ORIGINAL ARTICLE

Effects of biochar application on *Suaeda salsa* growth and saline soil properties

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Received: 26 July 2015 / Accepted: 5 February 2016

Abstract Pot experiments were conducted to study the effects of biochar application rates (5, 10, 20 g/kg) and types of wheat straw biochar (WS), corn stalk biochar (CS) and peanut shell biochar (PS) on *Suaeda salsa* (*S. salsa*) growth and properties of saline soil in Yellow River Delta. It was found that *S. salsa* yield increased from 11.7 to 115 % under WS application at a range of 5–10 g/kg compared with control. As biochar rate increased to 20 g/kg, the increment decreased to 102 %. The underground biomass of *S. salsa* only increased at 20 g/kg rate. The *S. salsa* growth respond to biochar followed the order of PS > WS > CS. Biochar application generally reduced saline soil pH and the effect was more obvious for WS. The content of total organic matter increased significantly at biochar rate of 10–20 g/kg. WS at higher application rate (20 g/kg) significantly increased available phosphorus content. At the same time, CS increased more available phosphorus content while PS decreased more of exchange sodium percentage. In generally, biochar application improved saline soil quality and enhanced plant growth although these effects should be tested in long-term period.

Keywords Biochar · Saline soil · Plant growth · Soil properties

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Introduction

As the deterioration of soil salinification in Yellow River Delta, lower soil organic carbon, nutrient content, water retention and microbial diversity have always been the limiting factors of saline soil, and eventually restrict the growth of plants (Wang et al. 2010). In recent years, lots of researchers found that the addition of biochar made from wastes of animals or plants in the absence of oxygen environment can increase soil carbon content, plant available nutrients, and especially improve plant growth in some kinds of soil (Atkinson et al. 2010; Major et al. 2010; Zhang et al. 2010; Almaroai et al. 2014; Xu et al. 2015). For example, Masto et al. (2013) found that 4 t/ha biochar application to acidic red soil improved the maize grain yield by 11.4 % above the control treatment. Zhang et al. (2012) observed that application of biochar to calcareous and infertile dry croplands enhanced maize yield by 15.8 and 7.3 % without N fertilization, and by 8.8 and 12.1 % with N fertilization under biochar rate of 20 and 40 t/ha, respectively. Hossain et al. (2010) and Chan et al. (2008b) also found that the yield increased with biochar application in acidic soil. However, negative effect of biochar addition on plant growth also been found in several studies (Asai et al. 2009; Belyaeva and Haynes 2012; Jones et al. 2012). Gaskin et al. (2010) discovered that grain yields decreased with 22 t/ha biochar rate in the fertilized treatments. Van Zwieten et al. (2010) found that biochar application significantly increased biomass in radish in the ferrosol with fertilizer. While, in calcarosol amended with fertilizer, biochar amendment reduced radish biomass.

Published online: 11 April 2016

So far, it has been known that the response of crop to biochar amendment depends on the chemical and physical properties of the biochar, climatic conditions, soil conditions and crop type (Yamato et al. 2006; Gaskin et al. 2010; Van Zwieten et al. 2010; Haefele et al. 2011). However, most of studies have been focus on acidic and humid tropical regions (Glaser et al. 2001; Van Zwieten et al. 2010; Yuan and Xu 2011; Wan et al. 2014). Very limited information has been reported on the saline soil. In this study, the effects of different biochar on *Suaeda salsa* (*S. salsa*) growth and saline soil properties were conducted to find out the agricultural profitability of biochar application to saline soil.

Materials and methods

The saline soil was sampled from ecological experimental station of coastal wetland located at Dongying Shandong, China. The soil is a typical saline alluvial soil (Fluvisols, FAO), which developed on loess material of the Quaternary period (Yao and Gu 1996). The sampled soil was sieved though 2-mm sieve as soon as possible and stored at 4 °C until analysis. The air-dried soil was used for the physical and chemical determination. The wheat straw, corn stalk and peanut shell were carefully rinsed with purified water and then air-dried and milled through 2-mm sieve before charring. The feedstocks were wrapped in aluminum foil to ensure an oxygen-limited atmosphere and underwent pyrolysis in muffle furnace at 300 °C for 4 h. Two comparison experiments were conducted: (1) different biochar addition rate: soil alone (CK), soil added with 5 g/kg (w/w) wheat straw biochar (5 g/kg WS), soil added with 10 g/kg (w/w) wheat straw biochar (10 g/kg WS), soil added with 20 g/kg (w/w) wheat straw biochar (20 g/kg WS); (2) different feedstock types biochar with equal amounts: soil added with 10 g/kg (w/w) wheat straw biochar(10 g/kg WS), soil added with 10 g/kg (w/w) corn stalk biochar (10 g/kg CS), soil added with 10 g/kg (w/w) peanut shell biochar (10 g/kg PS). The saline soil and biochar were thoroughly mixed and the water contents were retained at approximately 80 % water holding capacity with daily supplying. *S. salsa* was chosen as the test plant and was thinned to two plants per pot after emergence. 140 ml of Hoagland nutritional solutions containing 238 mg N/L, 31 mg P/L and 234 mg K/L was applied after germination and another 50 ml after seedling. After 2 months, aboveground and underground biomass was harvested, freeze-dried for 48 h and weighed.

The chemical characteristics of saline soil and biochar are listed in Table 1. The pH and electric conductivity (EC) was determined at 1:5 w/v for soil, 1:20 w/v for biochar and was analysed by pH meter (PHS-3C, Shanghai Leici instrument Inc. China) and portable multi parameter analyzer (DZB-718, Shanghai Leici instrument Inc. China), respectively. The adsorption capacity (AC) was measured by titration (GB/T12496.8-1999). The total organic carbon (TOC) was extracted by potassium dichromate-external heating method. The available phosphorus (AP) was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (soil: 1:10 w/v for 1 h, biochar: 1:100 w/v for 16 h). The total organic carbon (TOC) and available phosphorus (AP) were measured by UV-1800 spectrophotometer (Shimadzu, Kyoto, Japan). Cation exchange capacity (CEC) was determined with 1 M sodium acetate pH 8.2 (Lu 2000). The available potassium (AK) and exchangeable Na^+ ($Ex.Na^+$) were extracted with 1 M ammonium acetate at pH 7 (Lu 2000). CEC, AK and $Ex.Na^+$ were analyzed by Flame Atomic Absorption Spectrophotometer (Beijing Purkinje General Instrument Company, China). Exchange sodium percentage (ESP) was calculated as $Ex.Na^+$/CEC. All data were analyzed using Excel 2010 and SPSS 13.0 software. Treatment means were separated using *T* test and significant difference was One-way ANOVA analysis of variance ($P < 0.05$).

Results

The effects of biochar amendment on *S. salsa* total biomass, aboveground biomass and underground biomass

As shown in Table 2, *S. salsa* total biomass showed little influence ($P > 0.05$) at 5 g/kg biochar rate compared with control. As biochar addition reached 10 g/kg, *S. salsa* biomass increased 2.15 times as much as that of CK ($P < 0.05$). Although a slightly decreasing trend was found with biochar application rate increase to 20 g/kg, there was no significant difference between 10 g/kg WS and 20 g/kg WS addition ($P > 0.05$). Different feedstock biochars had different effects on *S. salsa* total biomass which followed the order of PS > WS > CS.

The effect of biochar addition on aboveground biomass of *S. salsa* growth was just like that of total biomass, whereas the trend of underground biomass was a little different (Table 2). Only 20 g/kg biochar addition significantly enhanced the growth of *S. salsa* roots. The underground biomass of WS, CS and PS was 10.4, 6.5 and 40.2 mg on average, respectively. Only the effect of PS addition on underground biomass reached a significant level ($P < 0.05$).

The effect of biochar addition on chemical properties of saline soil

It was found that biochar amendment resulted in saline soil pH reduction of 0.2 unit at 5–20 g/kg application rates

Table 1 The chemical properties of soil and biochar

	pH	EC (μS/cm)	AC (mg/g)	TOC (mg/g)	AP (mg/kg)	AK (mg/g)	CEC (cmol/kg)
Soil	8.59	239	–	4.24	12	698	11.4
WS	6.93	3975	415	490	237	9601	18.8
CS	8.01	5210	291	418	800	10,780	50.0
PS	7.71	404	345	382	314	3392	48.9

WS wheat straw biochar, *CS* corn stalk biochar, *PS* peanut shell biochar, *EC* electric conductivity, *AC* adsorption capacity, *TOC* total organic carbon, *AP* available P, *AK* available potassium, *CEC* cation exchange capacity

Table 2 Effect of biochar amendment on *S. salsa* growth

Different treatments	TB (g/pot)	AB (g/pot)	UB (g/pot)
CK	0.137a	0.129a	0.008a
5 g/kg WS	0.153a	0.143a	0.010a
10 g/kg WS	0.296b	0.285b	0.011a
20 g/kg WS	0.279b	0.260b	0.019b
10 g/kg CS	0.100a	0.096a	0.004a
10 g/kg PS	0.396c	0.367c	0.029c

Different letters indicate statistical difference at $P < 0.05$ ($n = 7$)

CK soil, *WS* soil addition with wheat straw biochar, *CS* soil addition with corn stalk biochar, *PS* soil addition with peanut shell biochar, *TB* total biomass, *AB* aboveground biomass, *UB* underground biomass

(Table 3) and no significant differences ($P > 0.05$) were observed in the treatments. A relatively lower dose of biochar rate (5 g/kg) showed little effects on soil organic carbon compared with control (Table 3). As biochar increased to 10 and 20 g/kg, TOC increased significantly ($P < 0.05$) by 70.4 and 187 %, respectively. The three feedstock biochars generally increased soil organic carbon and no significant difference among the three biochars were observed.

The content of available phosphorus (AP) was 14.5 and 16.8 mg/kg in 5 g/kg WS and 10 g/kg WS, although the effect was found to be insignificant ($P > 0.05$) compared with control. As biochar rate increased to 20 g/kg, AP reached to a significantly level (20 mg/kg). Among the different feedstock, 10 g/kg CS showed the most prominent effects. In all biochar, the contents of Available potassium (AK) was significantly higher than that in CK ($P < 0.05$).

It can be found that compared with CK, CEC increased slightly in all different biochar amendment treatments (Table 3). For example, CEC increased by 10.5, 15.9 and 38.4 %, respectively, with increasing WS biochar additive rate compared with CK. However, no significant differences were found between all the treatments and CK ($P > 0.05$).

As shown in Table 3, the difference of soil added with different biochar addition rate was insignificant ($P > 0.05$), although ESP of 20 g/kg wheat straw biochar treatment (20 g/kg WS) was in numerical reduction. Among the different raw materials biochar addition, a significant decrease of ESP was only observed in the treatment of PS amendment.

Discussion

The response of plant growth to biochar addition

The results showed that 10 g/kg wheat straw biochar increased dry matter of *S. salsa* by 102 %. Chan et al. (2008a) found that 50 t/ha biochar-amended treatment can increase dry matter of radish by 91 % in the presence of N fertilizer. It

Table 3 Effect of biochar amendment on saline soil chemical properties

Different treatments	pH	TOC (mgC/gsoil)	AP (mg/kg)	AK (mg/kg)	CEC (cmol/kg)	ESP (%)
CK	8.08a	5.75a	14.90a	338a	11.40a	26.95a
5 g/kg WS	7.88b	5.53a	14.50a	866b	12.60a	28.13a
10 g/kg WS	7.86b	9.80b	16.84a	902b	13.22a	27.04a
20 g/kg WS	7.85b	16.48c	19.98b	1327c	15.78a	24.05a
10 g/kg CS	8.05a	9.31b	21.65b	486d	14.36a	23.18a
10 g/kg PS	7.99a	8.36b	14.46a	444d	14.35a	18.13b

Different letters indicate statistical difference at $P < 0.05$ ($n = 7$)

CK soil, *WS* soil addition with wheat straw biochar, *CS* soil addition with corn stalk biochar, *PS* soil addition with peanut shell biochar, *TOC* total organic carbon, *AP* available phosphorus, *AK* available potassium, *CEC* cation exchange capacity, *ESP* exchange sodium percentage

Table 4 Correlation of biochar characteristics with *S. salsa* growth parameters

	pH	EC	AC	TOC	AP	Ex-Na$^+$	AK	CEC	Height	TB	AB	UB
pH	1											
EC	0.573	1										
AC	−0.699	−0.362	1									
TOC	−0.922**	−0.269	0.645	1								
AP	0.707*	0.704	−0.897**	−0.499	1							
Ex-Na$^+$	−0.356	0.535	0.386	0.647	0.024	1						
AK	0.541	0.984**	−0.298	−0.214	0.665	0.586	1					
CEC	−0.316	−0.553	−0.329	0.234	−0.323	−0.323	−0.531	1				
height	−0.504	−0.853**	0.539	0.325	−0.361	−0.361	−0.8*	0.335	1			
TB	−0.709*	−0.882**	0.706*	0.437	−0.239	−0.239	−0.813*	0.253	0.893**	1		
AB	−0.703	−0.924**	0.66	0.404	−0.311	−0.311	−0.87**	0.296	0.915**	0.993**	1	
UB	−0.321	−0.932**	0.174	−0.061	−0.558	−0.765*	−0.921**	0.486	0.841**	0.778*	0.831*	1

* $p < 0.05$, ** $p < 0.01$

was also found by Noguera et al. (2010) that rice yield increased by 166 % at 25 g/kg wood biochar addition. The plant growth increase may be linked to nutrient additions or retention with biochar addition (Lehmann et al. 2003; Steiner et al. 2007). In addition, biochar application may improve soil physical and chemical properties, such as reducing soil bulk density (Oguntunde et al. 2008), soil strength (Masulili et al. 2010; Lu et al. 2014), increasing soil CEC (Glaser et al. 2002; Rondon et al. 2007), water holding capacity (Liu et al. 2012) and so on.

However, excess input of biochar seemed to depress the growth of *S. salsa*. This phenomenon was also reported by Baronti et al. (2010) who found that the highest increase of ryegrass dry matter (+120 %) was obtained at a biochar rate of 60 t/ha and above this threshold, a general reduction of biomass was observed. Rajkovich et al. (2012) also found that biochar amendment rates above 26 t/ha did generally not improve corn growth. In our experiment, this can be explained lower nutrient availability at relatively higher pH value with higher biochar application.

Relationship between biochar properties and *S. salsa* growth

Correlation analysis between biochar characteristics and *S. salsa* growth parameters were conducted to find out the main biochar factors which affected *S. salsa* growth in saline soil (Table 4). It is noticeable that EC were negatively associated with *S. salsa* TB ($r = -0.882$; $P < 0.01$), AB ($r = -0.924$; $P < 0.01$) and UB ($r = -0.932$; $P < 0.01$). AK and pH was also negatively correlated with *S. salsa* TB, while AC was found to be positive correlated with *S. salsa* TB ($r = 0.706$; $P < 0.05$). In our experiment, the following order of PS > WS > CS was recommended for ameliorating saline soil because PS biochar has lowest EC (404 μS/cm) and WS biochar has relatively lower pH (6.93) and higher AC (415 mg/g) compared with CS. In generally, the short-term effect of different feedstock type biochar on plant growth was closely related to the raw material characteristics of biochar itself.

Biochar effects on saline soil properties

Biochar application increased organic C content especially at higher application rate. On one hand, there was higher organic carbon content in biochar. On the other hand, biochar addition was favorable for the formation of humus through adsorption and aggregation (Laird et al. 2009; Liang et al. 2010). There was no statistically significant difference was found between the three feedstocks (Sun et al. 2014).

The lower content of AP in WS indicated that only higher amount of biochar addition (20 g/kg) can significantly increase available phosphorus content of saline soil. The content of AK in soil (698 mg/g) was enough for plant demands. The additional input of AK added with biochar may inhibit plant growth because high osmotic will result in water uptake reduction (Rajkovich et al. 2012).

No statistically significant differences of CEC and ESP ($P > 0.05$) were observed between WS addition and control. Among three feedstock types biochar application, only PS treatment can significantly reduce saline soil ESP, which may be attributed to the lower exchangeable Na$^+$.

Conclusions

Our study revealed that the biomass of *S. salsa* increased proportionally with biochar addition rate although a slightly decrease occurred at higher biochar rate. The order of different raw material biochar addition effect on total biomass, aboveground biomass and underground biomass of *S. salsa* were peanut shell biochar > wheat straw biochar > corn stalk biochar. The positive crop responses from biochar application were related with not only the direct nutrient content increase with biochar amendment, but the indirect amelioration of saline soil properties. Biochar was extremely variable in nutrient composition and availability depending upon feedstock used. Therefore, according to different types of crop and soil, careful evaluation of biochar type should be considered before its application to agriculture.

Acknowledgments This research was supported by the National Natural Science Foundation of China (41501309;41171216), the National Basic Research Program of China (2013CB430403), Jiangsu Autonomous Innovation of Agricultural Science & Technology [CX(15)1005], Shuangchuang Talent Plan of Jiangsu Province, the Project of Ludong University (LY2015013) and 135 Development Plan of YIC-CAS.

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