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Negative interactive effects between biochar and phosphorus fertilization on phosphorus availability and plant yield in saline sodic soil

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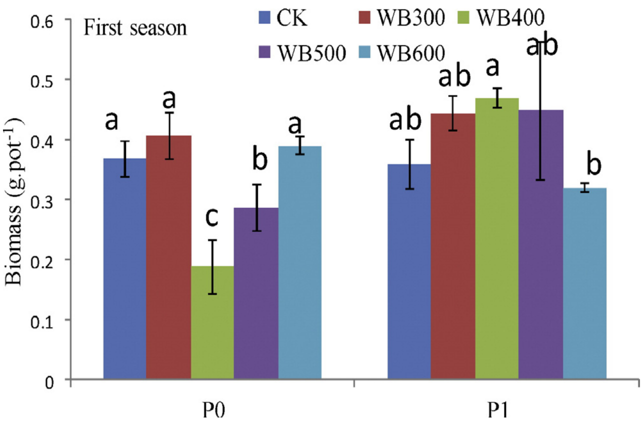
HIGHLIGHTS

- Lower pyrolysis temperature (<400°C) biochar retained P availability and increased plant growth.
- Negative (antagonistic) interaction occurred between biochar and P fertilization on the biomass production and plant P concentration
- Very limited utility value of biochar application occurred in saline sodic soil.

GRAPHICAL ABSTRACT



The growth of *Suaeda salsa* in biochar amended saline sodic soils with (P_1) or without (P_0) P fertilization.

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ABSTRACT

Little is known about the interactive effects between biochar application and phosphorus (P) fertilization on plant growth and P uptake. For this purpose, five wheat straw biochars (produced at 25 °C, 300 °C, 400 °C, 500 °C and 600 °C for 4 h) with equal P (36 mg kg^{-1}) amount, with and without additional P fertilization (100 mg kg^{-1}) were applied in a pot experiment to investigate the growth of *Suaeda salsa* and their uptake of P from biochar and P fertilization amended saline sodic soil. Soil P fractions, dry matter yield, and plant P concentrations were determined after harvesting 90 days. Our results confirmed that relatively lower pyrolysis temperature (<400 °C) biochar retained P availability and increased plant growth. The plant P concentration was significantly correlated with $NaHCO_3$-P_i ($P < 0.05$), and NaOH-P_i ($P < 0.1$) during early incubation time (4 days) for biochar amended soil. As revealed by statistical analysis, a significant ($P < 0.05$) negative (antagonistic) interaction occurred between biochar and P fertilization on the biomass production and plant P concentration. For plant biomass, the effects size of biochar (B), P, and their interaction followed the order of B × P (0.819) > B (0.569) ≈ P (0.568) based on the partial Eta squared values whereas the order changed as P (0.782) > B (0.562) > B × P (0.515) for plant P concentration. When biochar and P fertilization applied together, phosphate precipitation/sorption reaction occurred in saline sodic soil which explained the decreased plant P

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availability and plant yield in saline sodic soil. The negative interaction effects between biochar and P fertilization indicated limited utility value of biochar application in saline sodic soil.

1. Introduction

Biochar amendments increased soil phosphorus (P) availability and therefore enhanced crop productivity especially for low fertility soils (Blackwell et al., 2010; Biederman and Harpole, 2013; Marks et al., 2014; Subedi et al., 2016). When incorporation into soil, biochar can increase P availability through directly P release from biochar and indirectly improve P use efficiency by changes in soil pH, CEC, structure, decrease P leaching and affect soil P related microbial activity (Xu et al., 2014; Jiang et al., 2015; Zhai et al., 2015; Christel et al., 2016). Recent review suggested that P values of biochar as a soil amendment were highly depended on soil type, biochar type, and biochar rate (Scott et al., 2014). The positive effects of biochar on P values have been mostly proved in highly weathered acidic soil whereas the response was complex in alkaline soils (Lentz and Ippolito, 2012; Parvage et al., 2013). With increasing biochar rate, increase plant yield or soil available P were observed in acidic soil (Blackwell et al., 2010). In addition, animal-derived biochar supplied more P for plant growth than plant-derived biochar (Liang et al., 2014). In field experiment, different feedstocks biochar were generally tested for possible amendment in highly weather soils (Macdonald et al., 2014). However, pyrolysis temperature was more important factors determining the properties of biochar (Cantrell et al., 2012; Christel et al., 2013). The previous studies suggested that pyrolysis temperature greatly affect P transformation from crop residue to biochar (Xu et al., submitted). However, little is known about plant response to different pyrolysis temperature biochar based on a bioassay tests. This kind of information is important for the production and evaluation of biochar as a potential P source.

In addition, the directly P supply from biochar was thought to be short-lived and the indirectly P value with biochar application should to be verified in the long-term experiment (Wang et al., 2015). Most importantly, the interaction effects between biochar and P fertilizer need to be clarified in agricultural field (Tammeorg et al., 2014; Jain et al., 2016). Chan et al. (2010) found a positive (synergistic) interaction between biochar and nitrogen fertilizer where they found biochar application significantly increased plant yield and N (nitrogen) use efficiency in the presence of N fertilization (Chan et al., 2008). However, the interactive effects between biochar and P fertilizer on the plant growth and P use efficiency are still limited (Schulz and Glaser, 2012).

In acidic soils, the liming effects of biochar were regarded as the main mechanism for enhancing plant productivity (Farrell et al., 2014). However, in a saline sodic soil, we hypothesized that biochar application could reduce P availability and decrease crop productivity due to P sorption or precipitation. The present study aimed to compare the effects of biochar made at different pyrolysis temperatures on P availability and crop productivity, to evaluate the interaction effect between biochar and P fertilization on P availability and crop productivity.

2. Materials and methods

2.1. Experimental setup

The soil sample was collected from Dongying, Shandong Province, China. The soil properties and sampling process were detailed described in previous studies (Wu et al., 2014). The fresh wheat straw were carefully rinsed with purified water and then air-dried and milled through 2-mm sieve (WB25). The feedstock was pyrolyzed under oxygen-limited atmosphere in muffle furnace at 300 °C, 400 °C, 500 °C, and 600 °C for 4 h respectively (Xu et al., 2013).

Twelve treatment combinations (six pyrolysis temperature produced biochar with equal amount P of 36 mg P kg^{-1} of soil, with and without P fertilization (KH_2PO_4) of 100 mg P kg^{-1} of soil). The single biochar application referred as WB25, WB300, WB400, WB500, and WB600, respectively while biochar together with P fertilization defined as PWB25, PWB300, PWB400, PWB500, and PWB600, respectively. The treatments were arranged in a completely randomized block design with three replicates. For each treatment, three pre-germinated *Suaeda salsa* seeds were planted into a pot containing fresh soil (500 g oven-dry based). The *Suaeda salsa* was grown for 90 days in a glasshouse. 100 ml of Hoagland nutrient solution without P was added after plant transportation and the water was regularly supplied to ensure plant growth. The plant growth experiment was carried out for two growth season. After harvest, the plant was dried at 70 °C for 48–72 h in an oven. Another set of pot without plant growth was also carried out for soil P fractions at day 4 and day 90.

2.2. Chemical analysis

Soil P fractions was sequential extracted with a modified Hedley fractionation (Tiessen and Moir, 1993). Generally, 0.5 g samples were extracted step by step using 30 ml each of deionized water (18.2 MΩ), 0.5 M $NaHCO_3$, 0.1 M NaOH, 1 M HCl shaking for 16 h each addition.

Table 1
Effects of different biochar addition into saline soil on the soil phosphorus fractions. Data in the table indicate means of five replicates (±SD). Different letters on same column indicate significant difference at $P < 0.05$.

	H_2O-P	$NaHCO_3$-P_i	$NaHCO_3$-P_o	NaOH-P_i	NaOH-P_o	HCl-P_i
4 days						
CK	1.1 ± 0.1a	22.0 ± 0.7ab	38.3 ± 7.1bcd	6.7 ± 0.8ab	13.4 ± 7.0a	483.6 ± 18.9abc
WB25	0.7 ± 0.2a	19.3 ± 2.2a	52.2 ± 5.5e	7.7 ± 0.8ab	12.4 ± 0.9a	497.6 ± 10.3bc
WB300	1.6 ± 1.2a	34.4 ± 18c	29.0 ± 8.7b	8.9 ± 1.4b	18.3 ± 1.2a	493.4 ± 5.6bc
WB400	3.9 ± 0.1ab	29.0 ± 1.2abc	28.0 ± 2.4b	6.7 ± 0.8ab	20.7 ± 13.4ab	506.7 ± 28.6bc
WB500	4.7 ± 1.4ab	28.3 ± 1.6abc	31.1 ± 5.8bc	6.1 ± 0.4ab	15.5 ± 1.2a	510.9 ± 12.4c
WB600	7.2 ± 0.2b	28.8 ± 1.6abc	29.9 ± 6.0bc	5.8 ± 0.4ab	13.2 ± 0.6a	509.5 ± 1.4c
90 days						
CK	2.0 ± 1.0a	21.3 ± 2.6ab	39.8 ± 6.5bcde	7.3 ± 5.7ab	48.8 ± 19.0d	448.2 ± 53.8a
WB25	5.4 ± 0.5ab	19.8 ± 0.7a	34.8 ± 3.3bc	7.3 ± 1.3ab	39.5 ± 4.2 cd	470.3 ± 22.2ab
WB300	5.5 ± 0.2ab	26.6 ± 2.7abc	40.3 ± 13.3bcde	8.5 ± 1.8b	32.9 ± 4.4bc	488.6 ± 12.0bc
WB400	14.0 ± 8.2c	30.9 ± 2.5bc	15.7 ± 0.04a	5.8 ± 0.6ab	36.3 ± 3.8c	489.3 ± 26.9bc
WB500	16.9 ± 0.3c	32.5 ± 3.4c	43.4 ± 5.76cde	5.0 ± 0.6a	33.3 ± 3.1bc	480.5 ± 16.9abc
WB600	12.8 ± 5.8c	33.3 ± 3.1c	48.9 ± 12.1de	4.9 ± 0.6a	33.4 ± 6.5bc	470.7 ± 16.1ab