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Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress

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ABSTRACT

Salinity is one of the major threats to global food security. Biochar amendment could alleviate the negative impacts of salt stress in crop in the season. However, its long-term residual effect on reducing Na^+ uptake in latter crops remains unknown. A pot experiment with wheat was conducted in a greenhouse. The soil used was from an earlier experiment on potato where the plants were irrigated with tap water (S0), 25 mM (S1) and 50 mM (S2) NaCl solutions and with 0 and 5% (w/w) biochar amendment. At onset of the experiment, three different EC levels at S0, S1 and S2 were established in the non-biochar control (2.3, 7.2 and 10.9 dS m^{-1}) and the biochar amended (2.8, 8.1 and 11.8 dS m^{-1}) soils, respectively. A column leaching experiment was also conducted in the greenhouse to study the adsorption capacity of biochar to Na^+. The results indicated that biochar addition reduced plant sodium uptake by transient Na^+ binding due to its high adsorption capacity, decreasing osmotic stress by enhancing soil moisture content, and by releasing mineral nutrients (particularly K^+, Ca^{++}, Mg^{++}) into the soil solution. Growth, physiology and yield of wheat were affected positively with biochar amendment, particularly under high salinity level. It was concluded that addition of biochar had significant residual effect on reducing Na^+ uptake in wheat under salinity stress. However, more detailed field studies should be carried out to evaluate the long-term residual effects of biochar for sustaining crop production in saline soils.

1. Introduction

Biochar, a charcoal-like material, is increasingly used in agriculture with an intention to improve soil fertility, enhance crop productivity, sequester C in soil and to reduce greenhouse gases emission (Abiven et al., 2014; Cayuela et al., 2013; Lehmann, 2007; Pan et al., 2009; Zhang et al., 2010). It is produced by heating any kinds of organic waste (crop residue, animal or poultry manure etc.) at high temperature through process of pyrolysis. It is highly recalcitrant in nature because of its high aromaticity (Fang et al., 2014; Keith et al., 2011; Kuzyakov et al., 2014; Singh et al., 2012; Zimmermann et al., 2012). In literature, it is reported that biochar can sequester C in soil for 100–1000's years (Lehmann et al., 2006). In addition, studies have also shown that biochar can enhance plant growth either by its direct or indirect mechanism of actions. The direct growth promotion under biochar amendment involves supplying minerals nutrients, i.e. Ca, Mg, P, K and S etc., to the plant whereas, indirect mechanism involves improving soil physical, chemical and biological characteristics (Cheng et al., 2012; Enders et al., 2012; Peng et al., 2012; Sohi et al., 2010; Xu et al., 2012).

A number of studies have suggested that the effect of biochar is more pronounced in highly weathered, degraded and nutrient poor soils than in well-structured, nutrient rich and high quality soils (Abiven et al., 2014; Jien and Wang, 2013; Kookana et al., 2011). Moreover, biochar also received a great interest in remediating organic and inorganic contaminants due to its high adsorption capacity (Ahmad et al., 2014; Mohan et al., 2014; Samsuri et al., 2014; Uchimiya and Bannon, 2013). The adsorption capacity of biochar is determined by the feedstock and production conditions (Paz-Ferreiro et al., 2014; Uchimiya et al., 2011; Zhang et al., 2013). The favorable adsorption attribute of biochar includes its properties of high cation exchange capacity (CEC) and surface area.

Salinity is one of the major threats to global food security. According to a recent estimate, 1128 Mha (million hectares) land on global scale are affected by salinity and sodicity (Wicke et al., 2011). Salinity stresses plant by osmotic and ionic effects (Munns and Tester, 2008). Moreover, salinity also causes nutritional

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disorders (Grattan and Grieve, 1998) and limits the uptake of essential plant nutrients (K, Ca, Mg, P etc.) and ultimately results in crop yield losses. Different approaches have been used to reduce the impacts of salinity stress on plants; including developing salt resistant cultivars, using plant growth regulators (PGR) and inoculating seeds with halotolerant plant growth promoting rhizobacteria (PGPR) (Ashraf et al., 2008; Hanay et al., 2004; Zahir et al., 2012; Shahbaz and Ashraf, 2013; Akhtar et al. 2015b). Another important practice to mitigate the effect of salinity stress on crops is the application of organic conditioners, which can both ameliorate and increase the fertility of saline soils (Melero et al., 2007). Salt-affected soils generally exhibit poor structural stability due to their low organic matter content. Moreover, Lopez-Pineiro et al. (2007) reported increased residual effect of organic amendment in restoring degraded soils. Similar to organic matter, biochar, which is quite stable in soil, can also be used to ameliorate salinity stress by reducing Na^+ uptake in plants (Lashari et al., 2013; Lashari et al., 2014; Thomas et al., 2013). In a previous study, we have reported that incorporation of biochar into salt-affected soil could alleviate salinity stress in potatoes (Akhtar et al., 2015a) mainly because of its high salt (Na^+) adsorption potential. Similarly, Thomas et al. (2013) also noticed high salt adsorption potential of biochar. But, to trace the fate of this biochar-adsorbed Na^+ is very important before recommending its use in salt affected soils. Therefore, studying the residual effects of biochar on subsequent crops would give more clear understanding of the fate of the previously adsorbed Na^+. However, until now this aspect has not been addressed in literature.

The objectives of this study were to investigate the residual effects of biochar and to explore the underlying mechanisms for reducing Na^+ uptake and improving growth, physiology and yield of pot-grown wheat under salinity stress. It is anticipated that the research findings will be useful for formulating novel management strategies for improving crop production on salt affected soils.

2. Materials and methods

2.1. Experimental setup

The experiment was conducted in a greenhouse under controlled conditions at the experimental farm of the Faculty of Science, University of Copenhagen, Taastrup, Denmark. Spring wheat seeds (*Triticum aestivum* L. cv. Amaretto) were sown in each plastic pot (38 cm length, 29 cm width and 19.5 cm height) containing 19.6 kg. Soil used in pots was taken from our earlier experiment (Akhtar et al., 2015a) where the biochar was applied at the rate of 5% (B5) by weight. Non-biochar pots (B0) served as control. The soil was classified as sandy loam, having pH 7.2, total C 12.5 g kg^{-1}, total N 1.4 g kg^{-1}, water-soluble P 24 mg kg^{-1}, exchangeable Ca 3.0 mmol kg^{-1}, and exchangeable K, Mg, and Na <1.0 mmol kg^{-1}. Before filling into the pots, soil was mixed well and sieved by passing through 2 mm mesh. The basic biochar properties are shown in Table 1. Elemental composition of the soil prior to wheat sowing is provided in Supplementary material (Table S1).

2.2. Salinity treatments

Three different salinity levels (S0, S1 and S2) were established in a previous experiment by irrigating potato plants with 0 mM NaCl (tap water), 25 mM NaCl and 50 mM NaCl solution throughout the treatment period (Akhtar et al., 2015a). Moreover, irrigation was applied manually to approximately 90% of pot water holding capacity, so there was no leaching occurred during the experimental period (Akhtar et al., 2015a). At the same irrigation level, the salinity build-up in biochar amended pots was slightly higher than in non-biochar amended pots, i.e. at 0 mM, 25 mM and 50 mM NaCl irrigation, the averaged electrical conductivity (EC) levels were 2.3, 7.2 and 10.9 dS m^{-1} in the non-biochar treated soil and 2.8, 8.1 and 11.8 dS m^{-1} in the biochar amended soil, respectively. The ECs of soil and soil–biochar mixture were measured using conductivity meter in a 1:1 (soil: deionized water) soil saturated paste. The slight difference in ECs between amended and un-amended biochar treatment could have been due to higher concentration of nutrients in biochar as shown in Table 1.

Table 1
Physico-chemical properties of biochar. Elemental analysis was done by X-ray fluorescence (XRF) technique.

Attribute	Biochar
Bulk density, kg/m^3	302
Moisture content, %	19
Volatile solids, g/kg of total solid	906
Total C, g/kg of total solid	782
pH	7.6
EC, dS m^{-1}	0.71
Calcium, mg/kg	4430
Magnesium, mg/kg	910
Potassium, mg/kg	3570
Sulfur, mg/kg	90
Aluminium, mg/kg	25
Sodium, mg/kg	<10
Chloride, mg/kg	35
Zinc, mg/kg	75
Copper, mg/kg	17
Iron, mg/kg	76
Manganese, mg/kg	580
Lead, mg/kg	<10
Cadmium, mg/kg	<10
Nickel, mg/kg	<10

In the current experiment, all pots were irrigated with only tap water to 90% of pot water holding capacity throughout the experimental period.

2.3. Physiological measurements

Photosynthetic rate (A_n) and stomatal conductance (g_s) were measured twice (70 and 90 days after sowing) from the upper canopy fully expanded leaves (two leaves per plant and four leaves per treatments) between 11:00 and 14:00 h with a portable photosynthetic system (CIRAS-2, PP Systems, Hitchin, UK). Measurements were performed on 1.7 cm^2 of leaf area at 400 μmol ml^{-1} of CO_2 and 1000 μmol m^{-2} s^{-1} of photosynthetic active radiation (PAR). Chlorophyll content index (CCI) was measured with portable CCM-200 (Opti-Science, Tyngsboro, MA, USA) on the same leaves used for gas exchange measurement.

Chlorophyll fluorescence (F_v/F_m) was measured on the same leaves used for gas exchange measurement with a portable chlorophyll fluorometer (Handy-PEA; Hansatech Instruments, King's Lynn, Norfolk, UK), which emits light of 650 nm wavelength with an intensity of 2500 μmol photons m^{-2} s^{-1}. Measurements were taken from dark-adapted leaves (30 min dark adapted).

Stomatal density was calculated by counting number of stomata from the flag leaf images taken with a Dino-Lite digital microscope (AM411 series with ver. 1.4.1, Vidy Precision Equipment Co. Ltd, Wuxi, China) without damaging the leaves. The image of calibration sample was also saved to calculate the actual area of the image using AxioVision SE64 software (Rel. 4.4.3, Carl Zeiss Microscopy, Jena, Germany).

The flag leaf from each treatment was taken and then immediately dipped in liquid N and subsequently stored at −80 °C until analysis. Approximately 30 mg leaf sample was weighed and crushed using a precooled mortar and pestle by keeping pestle into ice to avoid heating during crushing in 2 ml deionized water. The samples were homogenized by shaking for 24 h at 4 °C and then