Chemosphere 142 (2016) 153–159

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Effect of biochar on reclaimed tidal land soil properties and maize (*Zea mays* L.) response

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HIGHLIGHTS

- Biochar amendment reduced ESP and increased the water stable aggregate percentage.
- Increases in the percentage water stable aggregate enhanced maize growth.
- Biochar decreased maize Na uptake resulting in decreased salt stress.
- Biochar was a beneficial amendment for reclaimed tidal land.

ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form 3 June 2015
Accepted 15 June 2015
Available online 29 June 2015

Keywords:
Biochar
Reclaimed tidal land soil
Water stable aggregate
Exchangeable sodium percentage
Salt stress

ABSTRACT

Reclaimed tidal land soil (RTLS) often contains high levels of soluble salts and exchangeable Na that can adversely affect plant growth. The current study examined the effect of biochar on the physicochemical properties of RTLS and subsequently the influence on plant growth performance. Rice hull derived biochar (BC) was applied to RTLS at three different rates (1%, 2%, and 5% (w/w)) and maize (*Zea mays* L.) subsequently cultivated for 6 weeks. While maize was cultivated, 0.1% NaCl solution was supplied from the bottom of the pots to simulate the natural RTLS conditions. Biochar induced changes in soil properties were evaluated by the water stable aggregate (WSA) percentage, exchangeable sodium percentage (ESP), soil organic carbon contents, cation exchange capacity, and exchangeable cations. Plant response was measured by growth rate, nutrient contents, and antioxidant enzyme activity of ascorbate peroxidase (APX) and glutathione reductase (GR). Application of rice hull derived biochar increased the soil organic carbon content and the percentage of WSA by 36–69%, while decreasing the ESP. The highest dry weight maize yield was observed from soil which received 5% BC (w/w), which was attributed to increased stability of water-stable aggregates and elevated levels of phosphate in BC incorporated soils. Moreover, increased potassium, sourced from the BC, induced mitigation of Na uptake by maize and consequently, reduced the impact of salt stress as evidenced by overall declines in the antioxidant activities of APX and GR.

1. Introduction

Tideland reclamation projects have been conducted actively in many countries to obtain additional areas for farmland and expanding industrial activities (Kim et al., 2011). In Korea, tideland reclamation projects were first initiated by the government in the 1960s (Lee and Lee, 1997) and were also popular in the late 1980s (1987–1989). The National Institute of Crop Science (NICS) had reported that a tidal area of around 784,000 ha was potentially available along the Korean peninsula of which more than 60% (508,000 ha) was suitable for development (NICS, 2012). Most of these developable tidelands were located along Korea's western and southern coast where the area is largely rias (drowned valleys), the ebb and flow of the tide is large and the sea shallow (Kim et al., 2011).

Reclaimed tidal lands have generally been used for agriculture; supplementing shortages in farm area triggered by increased

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http://dx.doi.org/10.1016/j.chemosphere.2015.06.041
0045-6535/

industrialization and urbanization. However, the reclaimed tidal lands were generally not suitable for cultivation because soils were high in exchangeable sodium percentage (ESP; 30–50%) and EC (20–40 dS m^{-1}). These unfavorable agricultural conditions were caused by high levels of exchangeable Na and soluble salts such as Cl^- and SO_4^{2-} (Cho et al., 2008) and groundwater having high EC (0.1–10.7 dS m^{-1}; average 1.68 dS m^{-1}) (Kim et al., 2003). Excessive amounts of Na disperse soil colloids and hence adversely influence soil physical properties such as aggregation, infiltration, permeability, and porosity. These physical properties can be improved as soil aggregation, monitored via water stable aggregates, increases through removal of Na^+ from the reclaimed tidal lands (Hanay et al., 2004). In addition, excessive salts cause phytotoxicity, nutrient imbalance and water deficiency (Ghoulam et al., 2002) which are all detrimental to long-term plant growth performance (Pierzynski et al., 2005). Therefore, in order to improve the productivity of reclaimed tidal land soil (RTLS), management protocols need to be developed to improve the soil properties of RTLS and to reduce salt accumulation in them.

Soil washing, through repeated flooding and drainage, and phytoremediation involving salt removal by salt tolerant crops have both been applied for the desalinization of RTLS (Lee et al., 2007; Sohn et al., 2010). Addition of organic and inorganic materials; such as compost, plant residue, gypsum, zeolite and bottom ash have also been demonstrated to improve the physical properties of RTLS (Baek et al., 2010; Kim et al., 2005; Lee et al., 2013; Son and Cho, 2009). For example, Lee et al. (2013) reported that bottom ash improved the infiltration rate of RTLS when incorporated at 80 m^3 ha^{-1}. However, the only amendments currently practically utilized for RTLS have been compost and gypsum, implying that many further investigations and performance evaluations of alternative amendments are required. Biochar is one such potential amendment material not previously considered.

Biochar is produced through pyrolysis of biomass in the absence of oxygen and has been used widely for carbon sequestration (Lehmann, 2007), where agricultural application has resulted in increased crop yields; induced by improving soil properties and fertility (Atkinson et al., 2010; Chan et al., 2007). Given that biochar has high concentrations of organic carbon, high porosity and surface area (Glaser et al., 2002; Lu et al., 2014), improvement in soil physical properties including soil structure and water holding capacity would be expected following incorporation into soils. For example, Uzoma et al. (2011) reported an increase in soil available moisture and a decrease in hydraulic conductivity of a saturated soil after application of cow manure derived biochar, resulting in increased maize growth. In addition, many previous studies have investigated the ability of biochar to adsorb and immobilize various environmental pollutants including heavy metals and pesticides (Ahmad et al., 2014; Beesley et al., 2011; Spokas et al., 2009) indicating that the biochar is suitable as an adsorbent to reduce toxicity.

Thus, the application of biochar may increase the productivity of RTLS via improvement in soil physical properties and mitigation of plant salt stress. Therefore, the current study examined the applicability of rice hull derived biochar to improve the physicochemical properties of RTLS together with plant response.

2. Materials and methods

2.1. Soil and amendment

Topsoils (0–20 cm) used for the pot trial were collected from a 19 year old reclaimed upland near the Seongmun Tide Embankment, located in Dang-jin, Chungcheongnam-do, Korea. Prior to use, collected soils were air-dried and sieved <2 mm via a stainless steel sieve. Rice hull derived biochar, pyrolyzed at 500 °C, was obtained commercially (DAEWON GSI, Korea). Bottom ash, which is generally used as a soil amendment, was also included in the pot trial for comparison as the industry benchmark material to evaluate the effectiveness of biochar on soil physical properties and plant growth. Bottom ash was obtained from the thermal power plant in In-cheon, Korea. Chemical properties of the biochar and the bottom ash are shown in Table 1. Prior to soil application, both biochar and bottom ash were finely milled using a mortar and pestle to pass a 2 mm sieve.

2.2. Pot trial

Soil was incorporated with either biochar (BC) or bottom ash (BA) at four different rates; 0%, 1%, 2% and 5% (w/w) and a portion of each soil mixture (5 kg) distributed to plastic pots (diameter 24 cm × height 24 cm). When soil was incorporated with amendments, each soil mixture was fertilized at a rate equivalent to 12 kg N ha^{-1}, 10 kg P ha^{-1}, and 10 kg K ha^{-1} using commercial fertilizer (Rajkovich et al., 2012). Following fertilizer amendment, water was supplied through the bottom of each pot and equilibrated for 3 days. Maize (*Zea mays* L.) seedlings (2 weeks old), previously cultivated on a commercial horticultural growing substrate in a growth chamber (day time, 16 h, 25 °C; night time 8 h, 18 °C; light, 500 mol m^{-2} s^{-1}), were then transplanted into each equilibrated pot. For each BC treatment a control in which no maize cultivation took place was used to allow for any possible changes in soil properties due to plant growth. All treatments were triplicated (total 33 pots). After transplanting seedlings, water was supplied through the bottom of each pot and then the maize seedlings were allowed to acclimatize in the soil mixture for one week prior to supplementing water with a 0.1% NaCl solution to simulate exposure to saline waters. The maize was cultivated for 6 weeks in a greenhouse (average daytime, 14 h, 30 °C; average nighttime, 10 h, 15 °C). During this period, 0.1% NaCl solution was supplied through the pot bottom, until the soil in the pots was fully saturated, at 3 day intervals to simulate natural reclaimed tidal soil conditions.

2.3. Preparation of soil and plant samples

The whole aboveground tissue of maize was harvested 7 weeks after transplantation. A proportion of the fresh sampled maize shoot was retained for determination of antioxidant enzyme activity while the rest of the shoot was washed once with tap water and twice with distilled water to remove any adhering soil particles prior to drying in a fan-forced drying oven at 70 °C for 72 h. Dried plant tissue was weighed, powdered and stored in a desiccator until analyzed for total nutrient and element contents.

Immediately after the shoots were collected, soil samples (1 kg) were collected from each pot, air-dried, and stored in a plastic container prior to analysis of physicochemical soil properties.

2.4. Soil analysis

Soil pH and EC were determined in a soil:distilled water suspension (soil to water ratio, 1:5) using a pH meter (S220, Mettler Toledo, Switzerland) and EC meter (S230, Mettler Toledo, Switzerland) after one hour shaking. Soil organic carbon was determined by the Walkley–Black method (Nelson and Sommers, 1996). Total nitrogen content was analyzed by the Kjeldahl method according to Bremner (1996), and available phosphorus was determined by the ascorbic acid method (Kuo, 1996). Exchangeable cations (Ca, Mg, K, Na) were analyzed by extraction with 1 N ammonium acetate (pH = 7.0), and then analyzed by atomic absorption spectrometry (AAS, Analyst 400, Perkin Elmer, U.S.A.).