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Effects of three different biochars amendment on water retention of silty loam and loamy soils

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ABSTRACT

A greenhouse experiment was conducted to investigate the effects of three biochar types on available water contents (AWC) of sandy loam and loamy soils. Two soil types, three different biochar types (BT), five biochar rates (BR) and five fertilizer levels (FR) were included in the study. The biochar types were produced from rice husk (RB), bean harvest residue (BB) and corn cobs (CB). All of the biochar types were either saturated with nutrient rich dairy effluent (DE) or kept unsaturated, while the soils with no addition of biochar types were regarded as control treatment. Winter wheat (*Triticum aestivum* L.) was grown for two seasons and soil sampling was done following each harvest. The mineral fertilizers were applied at the beginning of each season, while biochar types were applied only at the beginning of the experiment. Soil samples were analyzed for total porosity, water contents at field capacity and permanent wilting point, and thereby AWC was calculated. Soil type, BT, BR and FR had significant effect on water retention and total porosity. In both soil types, total porosity was significantly lower at higher BRs than control. The addition of different biochar types continually increased the AWC both in sandy loam and loamy soils, though the effect was more obvious in the loamy soils. However, comparing the water retention with 2.0 and 3.0% BR relative to the control in the first season, the increase rate of AWC was much higher in sandy loam soil compared to loamy soil. The aging of all three biochar types in second season caused to increase in AWC at a rate of 19.9% in RB, 6.0% in CB and 6.1% in BB. The results revealed that all biochar types used in this experiment can be utilized to improve AWC in both sandy loam and loamy soils.

1. Introduction

Improving water retention of arable soils in arid and semi-arid regions of the world is essential to maintain sustainability of food and fiber demands of increasing population mostly in undeveloped and developing countries. A number of attempts such as conservational tillage (Lampurlanés et al., 2016; Shao et al., 2016; Acar et al., 2017), mulching (Alliaume et al., 2017), application of organic materials (Alaoui et al., 2011) and the addition of fine particles (Shanmugam et al., 2004) have been made to improve the water holding capacity of soils. Significant positive influence on water holding capacity of coarse textured soils was reported by the addition of biochar as an organic amendment, primarily because of the increased soil porosity (Kammann et al., 2011; Liu et al., 2016; Igalavithana et al., 2017), which is a dynamic property and affected by several natural (plant roots, soil microorganisms) or anthropogenic factors (soil tillage) (Badorreck et al., 2012; Liu et al., 2017). Biochar, a pyrolyzed organic material can alter soil hydrology and retain large amounts of water and nutrients due to their high specific surface area (Van Zwieten et al., 2009) and porous structure (Basso et al., 2013). The water is retained in the pores inside biochar particles as well as pores created among soil and biochar particles (Liu et al., 2017). Thus, the effectiveness increases with the increasing rate of biochar application (Blanco-Canqui, 2017). Despite 4%–130% increase in available water content of soils by biochar amendment (Blanco-Canqui, 2017), the results are not consistent due to the differences in feedstock of biochar produced, production technology, application rate, size of particles applied, soil type and residence time in soil etc. (Major et al., 2012; Hardie et al., 2014; Obia et al., 2016; Liu et al., 2017; Mia et al., 2017). Some studies also reported a decline (Abel et al., 2013; Mukherjee and Lal, 2013) or no effect (Mollinedo et al., 2015; Hardie et al., 2014; Kinney et al., 2012) of biochar application on water retention of soils. When evaluating the published data on different biochar types, care should be given to type of feedstock and pyrolysis conditions, and the soil where biochar being applied (Andrenelli et al., 2016; Aller et al., 2017).

Water and nutrient holding capacity of soils with high sand contents

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are low which creates a severe risk of drought in arid and semi-arid regions, while leads to leaching in humid regions (Hardie et al., 2014). Higher water retention ability of biochar amended coarse textured soils helps to retain more amount of plant available water and decrease the leaching of nutrients (Hardie et al., 2014; Dokoohaki et al., 2017). Akhtar et al. (2015) stated the positive impact of biochar addition to saline soils by reducing the plant available uptake of Na and decreasing osmotic stress by improving soil moisture contents. The response of sandy soils to biochar treatment is faster and more prominent than clayey soils. Application of biochar in coarse textured soils is reported to reduce macropores in favor of meso and micropores, which improves the water retention (Dokoohaki et al., 2017; Blanco-Canqui, 2017). The biochar as an organic amendment acts as a cementing agent to form stable microaggregates (Nelissen et al., 2015), which facilitate the formation of micropores in soil and enhance water holding capacity of coarse textured soils (Bruun et al., 2014; Hansen et al., 2016). Biochar amendments, both fresh and aged significantly increased the water retention of maize grown clay loam soil compared to no biochar application, whereas had no influence on silt loam and variable impacts on sandy loam soils (Aller et al., 2017). In contrast to the obvious impact on coarse textured soil, addition of straw and wastewater sludge biochar to clay soil improved the formation of macroaggregates (5.0–2.0 mm and 0.25–0.5 mm), while microaggregate (< 0.25 mm) decreased with biochar amendment (Sun and Lu, 2014). Andrenelli et al. (2016) also stated the importance of biochar amendment for improving water and air movement in fine textured soils.

The characteristics of biochar types, particle size, shape, porous structure and size of pores largely depend on the type of feedstock and conditions of pyrolysis (i.e., temperature, heating rate, duration of retaining, etc.), which play a crucial role in water retention (Andrenelli et al., 2016; Liu et al., 2017). Water retention of different biochar types produced at high temperatures (< 500 °C) is higher due to being more hydrophilic than those produced at low temperatures. The removal of aliphatic functional groups at higher temperatures increases the affinity of biochar surfaces to water and plant nutrients (Gray et al., 2014). Most previous studies conducted to investigate the effects of biochar on soil water retention consisted of a specific type of biochar or a soil. However, the experiments conducted to compare the effects of different biochar types enriched with liquid manure on water retention of soils with different textures in the same experiment are limited. Therefore, a greenhouse experiment was conducted to compare the influence of different biochar types with various origins on water retention capacity of two different soil types. Data obtained in this study helps to compare the effects of same biochar on water retention in two different soils and also aid to infer the effect of three biochar types of varying origin on water retention under the same soil conditions.

2. Materials and methods

A greenhouse experiment was conducted to evaluate the influence of different biochar types on the soil water contents at field capacity and permanent wilting point during 2015/2016 wheat growing seasons. The greenhouse experiment was conducted at Gaziosmanpaşa University, Tokat, Turkey (40.33 °N, 36.47 °E, 640 m above sea level). The greenhouse was maintained at 33/22 (± 5) ºC day/night temperature. Free draining plastic pots (2.25 L; with an upper diameter of 17 cm, lower diameter of 12 cm and a height of 16 cm) were used in the experiments. The pots were filled with 1700 g of sandy loam and loamy soils. The experimental soils were collected from 0 to 30 cm of an apple orchard and a vegetable production field in Kazova Basin of Tokat province, Turkey. The long-term mean annual precipitation and air temperature were 440 mm and 12.4 °C, respectively (Gunal et al., 2007). The soils used in the experiment were sandy loam and loamy soils. The soils were formed over sediments deposited by Yesilirmak River and located on river bank and young terraces of the river. Both soils were classified as Fluvisols in World Reference Base (IUSS Working Group, 2015) and Typic Fluvents in Soil Taxonomy (Soil Survey Staff, 2014). Following collection, soils were air-dried and sieved to obtain a fraction of 2 mm to eliminate the skeleton materials.

Table 1

Selected basic properties of soils and biochars used in the experiment (Günal, 2018).

Property	Soil 1*	Soil 2**	RB	CB	BB
pH	8.22	8.15	9.8	7.70	8.90
EC^2 (dS m^{-1})	0.17	0.17	0.82	1.86	1.98
CaCO$_3$ (%)	2.36	5.98	N/A^1	N/A^1	N/A^1
Organic Matter (%)	1.13	0.75	N/A^1	N/A^1	N/A^1
Sand (%)	40.6	65.0	N/A^1	N/A^1	N/A^1
Silt (%)	39.2	23.0	N/A^1	N/A^1	N/A^1
Clay (%)	20.2	12.0	N/A^1	N/A^1	N/A^1
Texture Class	Loam	Sandy Loam	N/A^1	N/A^1	N/A^1
CEC^3 (me100 g^{-1})	N/A^1	N/A^1	15.2	10.2	74.7
Surface Area (m^2 g^{-1})	N/A^1	N/A^1	212	398	118
Total N (g kg^{-1})	N/A^1	N/A^1	450	770	190
Total C (g kg^{-1})	N/A^1	N/A^1	56000	85000	79000
C:N	N/A^1	N/A^1	124	110	416

*hereinafter will be written as loamy soil. **hereinafter will be written as sandy loam soil.

1N/A = Not Applicable; 2EC: Electrical Conductivity; 3CEC: Cation Exchange Capacity.

RB: Rice husk biochar, CB: Corn cob biochar, BB: Bean harvest residue biochar.

2.1. Production and characterization of biochar types

The biochar materials used in this study were rice husk (*Oryza sativa* L.), common bean (*Phaseolus vulgaris* L.) harvest residues and corn cobs (*Zea mays* L.). Biochars were produced by slow pyrolysis of feedstocks (maximum size 2 mm) at 500 °C in an ingeniously developed lab scale reactor. Slow pyrolysis process was characterized by slow heating rates (a rate of approximately 10 °C min^{-1}) and long residence times of biomass. The pyrolysis temperature was kept constant at 500 °C and biochar was held in the unit until pyrolysis gas disappeared. After heating for almost 4–6 hours, the biochars were allowed to cool to room temperature. The selection of these materials was purely based on their easy availability in Tokat province, Turkey.

The physicochemical characteristics of all biochar types are presented in Table 1. The pH and EC of the biochars were measured in deionized water at the ratio of 1:10 wtwt^{-1} ratio. The biochar samples were thoroughly mixed and allowed to equilibrate for 1 h; the pH and EC were then measured using an Orion 720 pH-EC meter with a combination electrode. The total C and N contents of were determined using a Leco CN-2000 analyzer (Leco Corp., St. Joseph, MI, USA) at 1200 °C. Ethylene glycol mono-ethyl ether (EGME) method was to measure specific surface area, typically used for soils (Cerato and Lutenegger, 2002). Cation exchange capacity was determined by ammonium acetate method (Chapman, 1965).

All biochar types were alkaline with pH values of 8.90, 7.70 and 9.80 for rice husk (RB), corn cobs (CB) and bean harvest residue (BB) biochar types, respectively. Depending on biomass and temperature in pyrolysis, the C/N ratio of biochar show high variability. The C/N ratio of biochars produced from 60 different biomasses ranged from 7 to 192 (Sun et al., 2017). The C/N ratios of biochars used in the experiment were 124, 110 and 416 for RB, CB and BB, respectively.

2.2. Treatments and experimental design

The experiments were laid out according to the factorial design. Soil textures were taken as main factor, biochar types as sub factor, biochar application rates as sub-sub factor, while fertilizer application rates were treated as sub-sub-sub factor. Thus, the experiment consisted of 2 soil type × 3 biochar types × 5 biochar application rates × 5 fertilizer application rates. All of the treatments had three replications and