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Effect of biochar application on soil hydrological properties and physical quality of sandy soil

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ABSTRACT

Biochar is a valuable soil amendment and is recognized to have a positive effect on the crop yield, soil quality, nutrient cycling, and carbon sequestration. However, the effect depends on biochar characteristics, doses, and soil properties. This paper reports the study on determination of the effect of different rates of biochar based on their size fractions on water retention characteristic of sand-based rootzone mixture characteristic for natural turfgrass rootzone.

The pot experiment was established using a soil with the texture of loamy sand. Mixtures of biochar and soil were prepared in March 2014. Biochar was produced using the straw of two species, namely miscanthus and winter wheat, by pyrolysis process at a temperature of 300 °C for 15 min with limited air access. Then, biochar particles were separated into three size fractions as follows: 0–500 μm, 500–1000 μm, and 1000–2000 μm. The following four biochar rates were used in this experiment: 0.5%, 1%, 2%, and 4%.

The results indicated that biochar application significantly improved the physical properties of the tested sandy soil. The basic soil physical parameters, such as bulk density and total porosity, were not only dependent on the rate but also on the size of the biochar. Small particles of biochar reduced the volume of soil pores in diameter below 0.5 μm but increased the volume of larger pores with a diameter 0.5–500 μm. Biochar application increased the available water content (AWC), especially when the finest fraction was used (0.064 cm^3 cm^{-3}). Biochar made of miscanthus was characterized by higher AWC (0.056 cm^3 cm^{-3}) than that made of winter wheat (0.050 cm^3 cm^{-3}). In the present study, the soil water repellency was increased by biochar application, but it was still classified as non-repellent.

1. Introduction

Sandy soil is widely used at sport facilities with natural turfgrass. Two national standards are commonly used in the construction of natural turf sport field: ASTM (American Society for Testing and Materials) standard F2396-04 (Standard Guide for Construction of High Performance Sand-Based Rootzones for Sports Fields) and DIN 18035-4 (German National Standard, Sports Grounds, Sports Turf Areas). According to these standards, a typical soil profile under sport turfgrass contains a sand-enriched rootzone laying on a coarse-textured sand or gravel. A high-quality turf is related to grass cultivars, climate conditions, and management practices and these factors are strictly connected to proper rootzone layer construction. The principal motivation of using high sand-content rootzone is to improve the mechanical properties of the turf surface and to resist soil compaction from frequent foot traffic. This is in contradiction with the main function of rootzone, which is to store water and nutrients (McCoy and McCoy, 2009). The coarse-structured soil with low clay content is characterized by a lack of water retention and nutrient-holding capacity necessary for healthy turf growth (Nasta et al., 2009).

The following two types of soil amendments are commonly used together with sand to make up the rootzone material: peat or soil, or both. The first is commonly known as an inorganic amendment with silt and clay texture modifying water retention (Li et al., 2000). The second is to increase the soil organic matter content, which improves water retention. According to Rawls et al. (2003), the soil water content at high water potential is affected more strongly by the organic carbon compared to that at low water potential. Water retention of coarse-textured soil is substantially more sensitive to the amount of organic carbon compared to fine-textured soils. In addition water retention of the soil mixture at the sport turfgrass can be improved by adding more organic materials such as sphagnum peat moss (Bigelow et al., 2004) or composted sewage sludge (Cheng et al., 2007). Some inorganic amendments have also been suggested for the use in these sandy soils, in order to increase plant available water including calcined clay,

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diatomite or zeolite (Li et al., 2000). A combination of these options allows to retain additional water, increasing the amount of available moisture in the root zone, and thus permitting longer intervals between irrigations (Shao-Hua et al., 2012; Andry et al., 2012). However, reports on the positive effect of organic matter on soil hydraulic properties are sometimes contradictory. Danalatos et al. (1994) did not find any effect of organic matter content on water retention. There is also risk that the organic substances content in soil and their biodegradation products may induce water repellency, particularly in coarse textured soils (Scott, 2000; McKissock et al., 2000). Thus new methods and materials for improving water retention are still being sought.

Biochar, the solid product of biomass pyrolysis, seems to be a very promising soil amendment. During the past decade, biochar has been considered as a valuable product that gives opportunities for soil improvement and carbon sequestration, in order to mitigate climate change (Peake et al., 2014). Biochar amendment has been shown to influence physical, chemical, and biological properties of soil (Mukherjee and Lal, 2013; Herath et al., 2013; Lehmann et al., 2011). This characteristic of biochar is mainly ascribed to its physical feature such as its highly porous structure and large surface area (Atkinson et al., 2010). The biochars are usually described as a heterogeneous material that varies in its chemical and physical properties. This variability depends not only on the parameters involved in pyrolysis but also on the materials used to produce biochar (Atkinson et al., 2010; Gundale and DeLuca, 2006).

Nutrient availability (N and P) in soil may be enhanced by the addition of biochar due to a higher cation adsorption (Liang et al., 2006) or by increased pH in acid soils (Van Zwieten et al., 2010). Lehmann et al. (2011) reported that the application of biochar affects the activity of soil fauna and microorganisms. However, the effect depends on biochar characteristics, doses, and soil properties (Jha et al., 2010).

According to Mahmood et al. (2003), the incorporation of biochar appears to have a positive impact on mycorrhizal fungi and also influences basic soil properties such as soil bulk density, texture, and particle size distribution. By adding biochar, soil macroporosity and mesoporosity were significantly increased and thus improved the aeration and water availability for plant roots (Herath et al., 2013). On the contrary, in their experiment on sandy soil, Jeffery et al. (2015) found no significant effects of biochar application on soil water retention. Similar results were observed by Hardie et al. (2014) with no improvement in soil moisture and water retention characteristics. Based on these results, the following question arises: What are the predominant factors that prevent improvement of soil quality by the addition of biochar?

We hypothesize that the biochar application has a positive effect on the soil pore system but this effect is modified by factors connected with biochar properties. The objective of this study was to determine the effect of different rates, size fractions, and feedstock type of biochar on water retention characteristics of sandy soil in a standard of natural turfgrass rootzone. The knowledge of the relationship between soil water retention properties and biochar amendments can be useful in turfgrass management particularly when concerned with irrigation.

2. Material and methods

2.1. Sample preparation

Biochar was produced from the biomass of the following two species: miscanthus *(Miscanthus × giganteus)* and winter wheat (*Triticum aestivum* L.). The straw of miscanthus and winter wheat was left to dry at ambient air temperature, ground to fine particles (<4 mm), and mixed to ensure homogeneity.

The plant material was pyrolyzed in an electrical laboratory furnace equipped with a temperature controller at a temperature of 300 °C for 15 min with limited air access (International Biochar Initiative, 2014). The speed of the furnace heating was 10 °C min^{-1}. The time and temperature were set according to the research of Lu et al. (2013), Mendez et al. (2013), Gondek et al. (2014) and Domene et al. (2015). The biochar was then removed from the furnace and cooled in a desiccator. It was then passed through sieves with a mesh size of 500, 1000 and 2000 μm, which resulted in three biochar classes of the following size fractions: 0–500 μm, 500–1000 μm, and 1000–2000 μm. All particles with a diameter above 2000 μm were removed from the samples. The basic chemical characteristics of the biochar are presented in Table 1. The dry weight content was determined in materials which had been shredded and sifted through a sieve with a mesh size 1 mm, and then dried at temperature of 105 °C for 12 h (Jindo et al., 2012). Content of total forms of carbon and nitrogen was determined on the vario MAX cube CNS analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). The total contents of other macroelements and trace elements were determined after incinerating the sample in a chamber furnace at 450 °C for 12 h and mineralization of the residue in a mixture of concentrated nitric and perchloric acid (3:2 v/v) (Gondek et al., 2016). Concentration of the studied elements in the obtained solutions was determined by inductively coupled plasma optical emission spectrometry Optima 7300 DV ICP-OES (Perkin Elmer, Waltham, Massachusetts, USA).

Soil with a texture of loamy sand (81% sand, 14% silt, and 5% clay) was used, according to the ASTM F2396-04 and DIN 18035-4 standards. Mixtures of biochar and soil were prepared in March 2014 with the following biochar rates (which equal biochar mass as a percentage of the whole sample mass): 0.5% biochar (B05), 1% biochar (B1), 2% biochar (B2), and 4% biochar (B4). The control object without biochar addition (B0) was also tested. The prepared samples were stored in 0.03 m^3 pots for three months with periodic watering to avoid drying. In June 2014, the soil samples were collected for laboratory measurements using steel cylinders with a capacity of 100 cm^3 (5.02 cm diameter and 5.05 cm height) in six replications for every treatment. To achieve a comparable and replicable compaction of samples, they were subjected to consolidation cycle under a static load of 600 g, based on to the method described by Stock and Downes (2008). These samples were used to determine soil water retention characteristics and bulk density (BD).

2.2. Measurements

The soil water retention curve (SWRC) was determined using pressure plates (Soil Moisture Equipment Corp., Santa Barbara CA, USA) according to Richards' method (Klute and Dirksen, 1986a). The soil samples were saturated with water for 24 h. After saturation, suction was successively applied to establish seven matric potentials, namely, −4, −10, −33, −100, −200, −500, and −1500 kPa. Van Genuchten (1980) parameters were fitted to the SWRC experimental data with the Mualem constraint (Mualem, 1986) (Eq. (1)):

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha h)^n\right]^{1-\frac{1}{n}}} \tag{1}$$

where θ is the soil water content (cm^3 cm^{-3}), h represents the matric potential (kPa), θ_s is the saturated water content (assuming equivalence with total porosity (TP)), θ_r is the residual soil water content, while α and n represent the model parameters. θ_r is associated with the immobile water present within a dry soil (at $h = \infty$). It was found that the value of the residual soil water content does not appear to greatly affect the goodness of fit of the SWRC (Fayer and Simmons, 1995; Leij et al., 2005; Haverkamp et al., 2005); therefore, in this study, $\theta_r = 0$ was set. The SWRC models (Eq. (1)) were fitted to the experimental water retention data using the method of nonlinear least-squares procedure in the statistical software package Statistica v. 10.0 (StatSoft Inc., Tulsa OK, USA). Based on this method, the following soil quality parameters were calculated:

(i) Field capacity (FC), defined as the equilibrium volumetric soil water content at −10 kPa matric potential