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Creeping bentgrass growth in sand-based root zones with or without biochar☆

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ABSTRACT

Organic amendments such as peat moss and various composts are typically added to sand-based root zones to increase water and nutrient retention. However, these attributes are typically lost within a few years as these amendments decompose. Biochar is a high carbon, porous coproduct produced from the pyrolysis of phytobiomass. Its unique porosity gives it excellent water and nutrient retention properties. Additionally, unlike other organic amendments, biochar is extremely resistant to microbial decomposition. Pure calcareous sand (control) or mixtures of three different biochars and sand at 1, 5 and 10% volume biochar/total volume were tested. Bulk densities decreased while percent pore space increased with the addition of all three biochars at all of the addition rates. Water retention was greater than the control in all but one of the biochar treatments, and several of the biochar mixtures had values for compaction resistance similar to pure sand. Creeping bentgrass (*Agrostis stolonifera* L. 'Pure Distinction') plant heights, root lengths, and fresh and dry weights were evaluated in mixtures grown hydroponically in polyvinyl chloride tubes (112 mm outside diameter × 99 mm inside diameter) filled 30 cm deep with 1 cm diameter pea gravel, over which 30 cm of either pure sand or sand/biochar mixtures were added to mimic a United States Golf Association root zone. Five weeks after seeding, plants grown in several of the biochar mixtures had significantly greater fresh and dry weights, shoot heights and root lengths than the control. Based on these results it appears that the addition of certain biochars would improve water retention and increase overall plant growth in sand-based root zones.

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1. Introduction

Current United States Golf Association (USGA) specifications recommend that golf green root zones consist of a minimum of 90% sand to provide sufficient drainage and reduce compaction. Because sand has inadequate water and nutrient retention for satisfactory turf performance, organic matter (most commonly peat) is added to the sand during golf green construction (USGA, 2004; McCoy, 2013). Other organic amendments, including various composts and municipal biosolids, have also been utilized and/or evaluated (USGA, 2004; Tian et al., 2008; Moody et al., 2009; McCoy, 2013). A disadvantage to these organic amendments is that they decompose over time, thereby reducing their effectiveness (Bigelow et al., 2004). Inorganic amendments including zeolites, diatomaceous earth and porous ceramic clays are marketed as non-biodegradable alternatives to peat (Bigelow et al., 2001, 2004; Ok et al., 2003). However, these materials have generally not been as effective as peat for enhancing water and nutrient retention (Bigelow et al., 2001, 2004; Waltz et al., 2003).

Biochar is the carbon-rich residual product created under anaerobic conditions by the pyrolysis of phytobiomass (Laird, 2008).

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However, biochar application to agricultural soils has had mixed results, partially due to variability in the biochars tested (Spokas et al., 2012). Physical and chemical properties (including bulk densities, micropore surface areas and potassium levels) of biochars produced from seven-year-old coppiced shoots varied considerably (Vaughn et al., 2015). Addition of biochar can greatly affect water and nutrient retention, especially in sandy soils. Biochars produced from black locust (*Robinia pseudoacacia* L.) wood at three different pyrolysis temperatures improved soil hydraulic properties and nutrient retention in a sandy soil (Uzoma et al., 2011). Application of fast pyrolysis switchgrass biochar at up to 25% (v/v) to sand-based turfgrass root zones greatly increased water retention, although at higher (>10%) concentrations decreased rooting depth (Brockhoff et al., 2010). An additional advantage of using biochar instead of other organic amendments is its resistance to microbial decomposition and hence longevity in soils (Sohi, 2012).

In the current study we compare the growth of creeping bentgrass (*Agrostis stolonifera* L.) in a 100% sand-based root zone with root zones amended with three biochars at rates of 1%, 5% and 10% (v/v) and chemically fertilized. Biochars chosen were a commercially-available fast pyrolysis biochar, a biochar produced from Paulownia (*Paulownia elongata* S.Y. Hu) trees, and a biochar produced from stems of Frost grape (*Vitis riparia* L.). These species were chosen because Paulownia is a fast-growing biomass crop for production in the southeastern U.S., while Frost grape is a C-3 photosynthesis woody vine. Ecological studies have indicated that the productivity of woody vines such as Frost grape are expected to benefit the most from elevated atmospheric carbon dioxide concentrations and will contribute to global biomass to a greater degree than other plants (Phillips et al., 2002; Ziska et al., 2007). Chemical and physical properties of the biochars, sand, and sand biochar mixtures (bulk densities, % pore space, water and nutrient retention and resistance to compaction) were also examined.

2. Materials and methods

2.1. Materials

Creeping bentgrass "Pure Distinction" seed was obtained from Tee-2-Green Corp., Hubbard, OR, USA. A commercially-available fast pyrolysis biochar (EG) was obtained from Evolution Group, Alton, IL, USA. Biochars were produced from tree trunks and branches from 6-year-old Paulownia trees (PE) grown at the Paulownia Demonstration Plot at Fort Valley State University, and from mature (greater than 2.5 cm diameter) stems of Frost grape (FG) using a top-lit updraft (TLUD) gasifier stove as described previously (Vaughn et al., 2015). Biochars were ground in a commercial blender and passed through a 2.00-mm sieve before being used in experiments. Calcareous sand with a pH of 7.7 meeting USGA standards (USGA, 2004) was purchased (Markham Peat, Inc., Le Claire, IA) and used in treatment mixtures. Sand was passed through a series of sieves to determine the particle size distribution of 1.1% very coarse, 74.4% coarse, 21.4% medium, 2.4% fine, 0.7% very fine and 0.1% silt and clay by volume.

2.2. Chemical and physical properties of the substrates and substrate components

Chemical analyses of the three biochars were conducted using the saturated media extract method with triplicate samples (Warncke, 1998). Bulk density and total porosity were determined by standard procedures (Milford, 2010), while pH values of sand, sand/biochar and sand/peat mixtures were evaluated by the methods of Torres et al. (2010) employing an AB 15 pH meter (Thermo Fisher Scientific, Waltham, MA, USA). All of these values were obtained on oven-dried material before application of fertilizer solution. Because the addition of any amendment can alter both the physical and chemical properties as well as the playability of golf greens (McCoy, 2013), we determined the compaction of the sand, sand/biochar mixtures and sand/peat mixtures. Compaction studies of the sand/biochar/peat mixtures were carried out at 10% moisture content to mimic field-like conditions. A positive pressure circular die mold (Carver Inc., Wabash, IN, USA) with an interior diameter of 28.3 mm was used to measure compaction; 10 g of each sand/biochar/peat sample was placed in the mold and then 13.34 kN of force was applied for 1 min. The distance traveled by the upper piston was then recorded as the compaction distance. The water retention capacity of each substrate was determined using a gravimetric method (van Genuchten, 1980) which estimated the soil moisture content 24 h after saturation by subtracting the wet weight from the dry weight. Equal volumes (10 mL) of substrate were placed into individual 20 mL plastic germination cups lined with filter paper. The dry weight was measured, and then the cup was filled with 10 mL of water. Excess water was allowed to drain for 24 h and then wet weight measurements were recorded. The difference between the two measurements were used to estimate the amount of water retained by each substrate. The average amount of water retained was estimated from three independent samples of the same substrate. The substrate nutrient retention capacity was indirectly estimated from the quantity of nutrient leaching (Lehmann and Schroth, 2003). The amount of nutrients within each solution was determined by measuring the conductivity of the solution using a MultiLab 4010-1c conductivity meter (YSI, Yellow Springs, OH, USA). The conductivity of Hoagland's nutrient solution was approximately 650 μS cm^{-1} and deionized (DI) water measured at 0 μS cm^{-1}. To determine the contribution of nutrients within the substrate prior to the addition of the nutrient solution, 25 mL of DI water was allowed to percolate through a 10 cm column packed with 10 mL of substrate and the conductivity of the effluent was measured. Hoagland's solution (25 mL) was then passed through the substrate column and conductivity of the effluent was measured. The conductivity of Hoagland's solution (650 μS/cm) and the conductivity of the effluent from DI water were summed, to estimate the maximum total amount of nutrients (both inherent amounts and added by the nutrient solution and) within the substrate. The quantity of nutrients retained was then calculated by subtracting the conductivity measurement of the effluent from the Hoagland's solution which percolated thought the substrate from the estimated total.

2.3. Plant experiments

Sand and biochar mixtures were prepared using a cement mixer, with the biochar mixtures lightly wetted with deionized water during mixing to assist in even distribution of the biochar in the sand. Polyvinyl chloride tubes (71.1 cm height × 1.12 cm outside diameter × 0.99 cm inside diameter) were filled 30 cm deep (2.5 L volume) with 1 cm diameter pea gravel to mimic a United States Golf Association root zone (Brockhoff et al., 2010). Over this 30 cm (2.5 L) of pea gravel, either sand (control) or the biochar/sand mixtures were added. Seven hundred and fifty milliliter of DI water containing 0.736 g L^{-1} of a complete hydroponic fertilizer (16-4-17 Hydroponic Fertilizer, Oasis Grower Solutions, Kelowna, British Columbia, Canada) were poured into each tube, for a rate of 5.0 g N m^{-2}. This amount was sufficient to saturate all of the treatments with liquid as well as preconditioning the biochar with nutrients. Forty-seven milligram (6 mg m^{-2}) of creeping bentgrass seed was applied to the surface of the sand or sand-biochar mixtures and covered with 4 g (approximately 1 cm thickness) of a commercial hydromulch (HydroStraw® Original Formulation, HydroStraw LLC, Manteno, IL) which both prevented the seed from drying out as