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Biochar-organic amendment mixtures added to simulated golf greens under reduced chemical fertilization increase creeping bentgrass growth☆

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ABSTRACT

Simulated golf greens were used to test the growth of creeping bentgrass (*Agrostis stolonifera* L. '007′) receiving suboptimal chemical fertilization in sand based substrates amended with 15% peat (control), a commercial biochar, a commercial biochar-compost mixture (CarbonizPN-Soil), or seven formulated biochar-compost mixtures. Physical and chemical properties including pH, bulk density, pore space, compaction distance, nutrient content and water/nutrient retention capacity varied among the mixtures. The heights, root lengths, and fresh and dry weights of creeping bentgrass plants grown in polyvinyl chloride tubes containing the different substrate mixtures mimicking a United States Golf Association root zone were evaluated and compared. Forty days after seeding, plants grown in 5% biochar and 10% Metropolitan Water Reclamation District of Greater Chicago biosolids had significantly greater fresh weights, dry weights, and shoot heights than the control. Dry weights and shoot heights were also higher than the control in bentgrass grown in the 15% CarbonizPN-Soil mixture. Based on these results the addition of these two biochar-organic amendment mixtures would improve overall plant growth in sand-based root zones under reduced chemical fertilization.

1. Introduction

Modern golf putting green root zones are constructed using sand to provide a smooth putting surface, prevent compaction, and promote rapid water drainage. Because sand has inherently poor water and nutrient retention properties, organic matter such as sphagnum peat is typically included in the construction of new golf greens (USGA, 2004; McCoy, 2013). However, after peat is harvested, the cutover peatlands are a large and persistent source of atmospheric CO_2, primarily due to increased soil organic matter decomposition and reduced carbon fixation from new vegetative growth (Petrone et al., 2003; Waddington et al., 2010). Other organic amendments, including various composts and municipal biosolids, have also been examined as more carbon-neutral replacements for peat, with the additional benefit of supplying nutrients (Kaminski et al., 2004; Tian et al., 2008; Aamlid and Hanslin, 2009; Moody et al., 2009; McCoy, 2013; Aaamlid et al., 2014). Nevertheless, as putting greens age, these organic amendments decompose, and most of the remaining organic material from grass decomposition accumulates near the surface (Murphy et al., 1993; Habeck and Christians, 2000; Curtis and Pulis, 2001; McClellan et al., 2009; Lewis et al., 2010). This causes water and nutrients to be retained in this area, resulting in shallow-rooted plants which are much more susceptible to episodes of drought. Inorganic amendments that resist degradation and have high water and nutrient retention, including diatomaceous earth, porous clays, zeolites and volcanic pumice, have also been examined as peat replacements (Bigelow et al., 2001; Ok et al., 2003; Waltz et al., 2003; Bigelow et al., 2004; Volterrani and Magni, 2012).

The addition of charcoal to new golf greens for improving porosity and overall properties was first suggested over 85 years ago (Morley,

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1929). Several recent studies have examined biochar (agricultural charcoal) as an amendment to golf greens (Brockhoff et al., 2010; Carey et al., 2015; Vaughn et al., 2015a). Unlike other organic amendments, biochar is highly resistant to microbial decomposition and therefore would be expected to have great longevity in root zones (Laird, 2008; Sohi, 2012). Furthermore, application of biochar to soils has been shown to improve runoff water quality and retention of nutrients (Beck et al., 2011; Knowles et al., 2011; Uzoma et al., 2011; Bruun et al., 2014). Because sand-based root zones require high fertilizer and pesticide inputs, leaching of these compounds into groundwater is of serious concern (Aamlid, 2005; Larsbo et al., 2008; Głąb et al., 2016). Leaching of excess fertilizer into bodies of water can lead to eutrophication, such as is occurring in the Gulf of Mexico and the Great Lakes. Because of this, several U.S. states are enacting legislation restricting the application of fertilizer to non-agricultural lands, with special restrictions concerning nitrogen and phosphorus fertilizer applications. As an example, the Fertilizer Use Act of 2011 enacted by the state of Maryland prohibits the application of phosphorus fertilizers to non-agricultural land (this includes private lawns, golf courses, public parks, athletic fields and cemeteries) unless a soil test result indicates it is needed, while also greatly restricting amounts of nitrogen fertilizer applied (http://mda.maryland.gov/resource_conservation/Documents/fertilizerwebpage.pdf). A major objective of our research is to find root zone amendments which would allow reduced rates of fertilizer while still allowing optimal turfgrass growth. Preliminary greenhouse studies found little or no differences in the growth of creeping bentgrass growth when different root zone organic amendments were employed and chemical fertilizers were used at recommended rates. Therefore for the research presented in this paper a reduced level of chemical fertilizer was used.

In this study we compare the growth of creeping bentgrass (*Agrostis stolonifera* L. '007′) in 85% sand-based root zones that have been amended with mixtures of peat, peat/biochar, biochar, and biochar/composts under reduced chemical fertilization. Chemical and physical properties of the biochars, sand, and sand biochar mixtures (bulk densities, % pore space, pH, inherent nutrient content, water and nutrient retention, and resistance to compaction) were also examined.

2. Materials and methods

2.1. Materials

Creeping bentgrass '007′ seed was obtained from Seed Research of Oregon, (Tangent, OR, USA). Biochar produced by pyrolysis of Southern yellow pine at 400 °C was supplied by Mirimichi Green Express (Castle Hayne, NC, USA), and sphagnum peat moss was purchased from SunGro® Horticulture, (Agawam, MA, USA). Calcareous sand with a pH of 8.1 and particle size distribution meeting USGA standards (USGA, 2004) was purchased (Galena Road Gravel, Chillicothe, IL, USA) and used in treatment mixtures. Sand was passed through a series of sieves to determine the particle size distribution of 1.5% very coarse, 54.6% coarse, 39.4% medium, 3.3% fine, 1.1% very fine and 0.1% silt and clay by weight. Pea gravel meeting USGA standards was obtained from Kickapoo Sand & Gravel, Princeville, IL, USA. Organic composts tested were: anaerobic biosolids (MWRD biosolids) and anaerobic biosolids mixed with yard-waste compost [MWRD compost; both obtained from the Metropolitan Water Reclamation District (MWRD) of Greater Chicago, Chicago, IL, USA]; Humus compost (The Humus Compost Company LLC, Harrisonburg, VA, USA); worm castings (Wiggle Worm Soil Builder, UNCO Industries, Inc., Union Grove, WI, USA); vermicompost (TerraVesco, Sonoma, CA, USA); Organimix compost (Midwest Organics Recycling LLC, McHenry, IL, USA); and CabonizPN-Soil (a mixture of 50% biochar and 50% composted swine manure; Mirimichi Green Express).

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

Chemical analyses of the biochar, peat and composts were conducted using the saturated media extract method with triplicate samples (Warncke, 1998). Elemental composition data of the biochars (using approximately 2 mg of biochar for each measurement) for percent carbon, hydrogen, sulfur, nitrogen and oxygen were obtained using a Perkin Elmer 2400 CHNSO series II Analyzer (Norwalk, CT), with cysteine as the standard. Ash content was determined using a Q2950 (TA Instruments, New Castle, DE) thermogravimetric analyzer by heating to 1000 °C at 10 °C min^{-1} under an air atmosphere. Surface area measurements were performed on a Quantachrome ASiQ (Quantachrome Instruments, Boynton Beach, FL, USA). Samples were degassed at 200 °C for 10 h prior to analysis. Surface areas were determined at −196 °C using N_2 as the analytical gas in a relative pressure range of 0.01–0.30 using the BET method for total surface area calculations. The pressure range used in the calculation for each sample was chosen based on the best linear fit for points in the 0.025–0.30 range (Brunauer et al., 1938). Micropore surface areas were determined using the *t*-method over a relative pressure range of 0.15–0.30. The data were analyzed using the de Boer model for the layer thickness equation. (Lippens and de Boer, 1965). Bulk density and total porosity were determined by standard test methods as previously described (Vaughn et al., 2015a), 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.

Compaction of the root zone mixtures were carried out at 10% moisture content to simulate field conditions and water retention capacity of each substrate was determined as described in Vaughn et al. (2015a). The substrate inherent nutrient content and retention capacity was indirectly estimated from the quantity of nutrient leaching (Lehmann and Schroth, 2003). The amount of nutrients within each effluent solution was estimated by measuring the conductivity of the solution using a MultiLab 4010-1c conductivity meter (YSI, Yellow Springs, OH, USA). To initially determine the differences in inherent nutrient content due to the variable compost amendments, 50 mL of deionized (DI) water 0 μS cm^{-1} was allowed to percolate through 20 mL of substrate and the conductivity of the effluent was measured. Hoagland's solution (25 mL) was then passed through the substrate column and the effluent conductivity was measured. Measurements were taken in triplicate from independent preparations of substrate mixes. The conductivity of Hoagland's solution (650 μS cm^{-1}) 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) within the substrate. The change in conductivity due to nutrient retention was then calculated by subtracting the conductivity measurement of the effluent from the Hoagland's solution which percolated through the substrate from the estimated total.

2.3. Plant experiments

Polyvinyl chloride tubes (71.1 cm height × 11.2 cm outside diameter × 9.9 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 mixtures of 85% sand (v/v) uniformly mixed with 15% (v/v) of the organic amendments. These organic amendments were as follows: 15% peat (control); 15% biochar; 5% biochar/10% peat; 5% biochar/10 MWRD biosolids; 5% biochar/10% MWRD compost; 5% biochar/10% vermicompost; 5% biochar/10% Organimix; 5% biochar/10% Humus; 5% biochar/10% worm castings; 15% CarbonizPN-Soil. Mixtures were prepared using a cement mixer, with the combined materials wetted