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Evaluation of biochar-anaerobic potato digestate mixtures as renewable components of horticultural potting media☆

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ABSTRACT

Various formulations are used in horticultural potting media, with sphagnum peat moss, vermiculite and perlite currently among the most common components. We are examining a dried anaerobic digestate remaining after the fermentation of potato processing wastes to replace organic components such as peat moss, and biochars produced from several feedstocks as replacements for inorganic media components such as vermiculite and perlite. Biochars were prepared using a top-lit updraft pyrolytic stove from wood pellets, pelletized wheat straw and field pennycress presscake. Biochar yields and heats of combustion were highest with the field pennycress presscake and lowest with the wood pellets. Because all three biochars had basic pHs, they were treated with citric acid solutions to lower pH values to 6.0 before being used in plant experiments. All three acidified biochars were combined in 1:1 ratios with the digestate and compared against a 1:1 sphagnum peat moss:vermiculite control substrate containing slow-release chemical fertilizers. All digestate:biochar substrates had higher bulk densities and levels of soluble salts than the control. Greenhouse experiments were conducted using tomato (*Solanum lycopersicum* L.) and marigold (*Tagetes erecta* L.) plants grown in 2.5-L pots. Combining potato anaerobic digestate with acidified wood pellet biochar resulted in increased growth of tomato plants as compared to the peat:vermiculite control, while the digestate:acidified wheat straw pellet biochar substrate was equal to the control for marigold growth. Plants of both species grown in the digestate:pennycress presscake biochar substrate had less growth than the control. From these results it appears that both the digestate:acidified wood pellet biochar and the digestate:acidified straw pellet biochar would likely be acceptable alternatives to peat:vermiculite substrates, and would also be an option for certified organic producers.

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1. Introduction

Commercial container production of horticultural plants primarily utilize soilless substrates, which include organic materials such as peat moss, tree barks and composts, and inorganic materials such as vermiculite, perlite and sand (Bilderback et al., 2005; Nelson, 2011). In 2011 nearly 5.2 million m^3 of sphagnum peat moss was consumed in the United States for horticultural applications, with approximately 96% of this imported from Canada (USGS statistics http://minerals.usgs.gov/minerals/pubs/commodity/peat). Peatlands in the northern hemisphere store approximately one-third of world's CO_2 (Gorham, 1991), and there is increasing public concern over their destruction during peat harvest (Barkham, 1993; Robertson, 1993; Zaller, 2007; Blok and Verhagen, 2009; Jayasinghe et al., 2010). The utilization of farm, industrial and consumer waste by-products as components of nursery substrates

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has been extensively investigated during the past several decades, with a wide variety of materials having been examined (Chong, 2005; Krucker et al., 2010; Vaughn et al., 2013).

Biochar is the carbon-rich, solid residual product resulting from the pyrolysis (heating materials in the absence of oxygen) of various biomass feedstocks where it can be added to agricultural fields to increase water and nutrient retention, lower bulk density and improve pH values (Laird, 2008; Beck et al., 2011; Altland and Locke, 2012; Sohi, 2012; Spokas et al., 2012). Biochar produced from wood pellets (composed of sawdust from several conifer species) decreased tomato seedling wilting due to water stress when mixed at 30% (v/v) with sandy soils (Mulcahy et al., 2013). When substituted for peat moss in potting substrate mixtures in rates up to 15% (v/v), biochars (without acid treatment) produced from hardwood pellets and pelletized wheat straw were similar in performance to mixtures containing only peat moss (Vaughn et al., 2013). Unfortunately, when we tested biochars at higher levels than 15% there was an increasing decrease in plant growth, possibly due to overly high pH values (Vaughn, unpublished data). If pH values of biochars were lower, then higher percentages of biochar could be used. Santiago and Santiago (1989) found that washing biochar with water before use decreased the biochar pH as well as allowing the biochar to more readily absorb water.

During the processing of potatoes in the United States and Canada, up to 50% of the total can be unsuitable for human consumption (Charmley et al., 2006). This waste can be fed to livestock, applied to agricultural fields as fertilizer, or dumped in landfills (Charmley et al., 2006; Nelson, 2010). During the past decade there has been increasing global interest in using these wastes for bioenergy generation (Kryvoruchko et al., 2009; Arapoglu et al., 2010; Singh et al., 2012; Wang, 2013). In June of 2009, Cavendish Farms© opened a facility to convert solid potato processing wastes to biomethane gas via an anaerobic digestion process at its plant in New Annan, Prince Edward Island (http://www.cavendishfarms.com/uploadedFiles/Grocery_Products/Canada/About_Us/Sustainability/Fact-Technical%20sheet_v6.pdf). After fermentation is complete a wet digestate remains which can be applied to agricultural fields as fertilizer. When dried, we found that the digestate had similar physical characteristics (bulk density, water retention, pH value) to peat moss, but unlike peat contained adequate levels of essential nutrients required for plant growth, allowing it to serve not only as a substrate component but also as a complete organic fertilizer.

In this study, we compare tomato and marigold seedlings grown in a standard 1:1 peat moss:vermiculite substrate containing added chemical fertilizer against three substrates prepared from potato digestate combined with the three biochars without any additional chemical fertilizer.

2. Materials and methods

2.1. Materials

Biochars were produced using a top-lit updraft cookstove as described previously (Vaughn et al., 2013) from commercially available wood pellets (WP; Indeck Ladysmith, Ladysmith, WI, USA), pelletized wheat straw (PS; StrawNet® Pelletized Straw Hydromulch, Hydrostraw LLC, Manteno, IL, USA), and from pennycress presscake (PC), which was prepared as described by Evangelista et al. (2012). The three biochars were then treated with food-grade anhydrous citric acid (Jungbunzlauer Inc., Newton Centre, MA, USA) solutions to bring the pHs of all three biochars to 6.0. The acid treatment caused some of the biochar pellets to break into smaller pieces, so before being used in substrates, only biochar pieces which did not pass through a 2 mm sieve (Humboldt Standard Sieve, Humboldt Manufacturing Co., Elgin, IL, USA) were used in experiments. Anaerobic potato digestate (afterwards referred to as digestate) prepared by a proprietary anaerobic fermentation process was obtained wet from Cavendish Farms©, Dieppe, New Brunswick, CA, and air-dried at 25 °C for three weeks before use. RePeet™, a commercially available peat moss replacement produced by the anaerobic digestion of dairy cow manure, was included for bulk density comparison, and was obtained from Organix, Walla Walla, WA, USA. Sunshine® vermiculite (medium particle size) was obtained from Sun Gro Horticulture Distribution Inc., Bellevue, WA, USA. Ferti lome® sphagnum peat moss was obtained from VPG, Bonham, TX, USA. Vermiculite and peat moss were combined in a 1:1 (v:v) ratio, and supplemented with Osmocote® 14-14-14 and Micromax® chemical fertilizers (The Scotts Company LLC, Maryville, OH, USA) at rates of 23 and 3.5 g fertilizer kg^{-1} potting mix, respectively. Dolomitic limestone (Organic Garden Lime, The Espoma Co., Millville, NJ, USA) was added to the control substrate at the rate of 80 g kg^{-1} potting mix. The three biochars were mixed with digestate at 1:1 (v:v) ratios, with no additional fertilizer or limestone added to the formulations.

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

Chemical analyses of the potato digestate and of the three acidified biochars were conducted using the saturated media extract method with triplicate samples (Warncke, 1998). Potting substrate physical properties were determined by methods using North Carolina State University (NCSU) porometers (purchased from NCSU Horticultural Substrates Laboratory, Raleigh, NC, USA) for bulk density, total porosity, container capacity and air space (Fonteno and Harden, 2003), while pH and electrical conductivity (EC; a measure of the concentration of soluble salts) were evaluated by the methods of Torres et al. (2010) employing a HI 9813 portable EC meter (Hanna Instruments, Woonsocket, RI, USA) and an AB 15 pH meter (Thermo Fisher Scientific, Waltham, MA, USA). Biochar yields were calculated from triplicate samples by the formula: weight of oven-dried biochar after acidification/weight of oven-dried parent substrate X 100%. The gross calorific value (MJ kg^{-1}) of the samples was measured ($n = 3$) using an IKA (Wilmington, NC) model C2000 automated bomb calorimeter with a D-Neslab RTE 7.0 cooler (23.5 °C) and paraffin ignition strips, according to ASTM method D5468. Solid samples (0.2 g) were pressed into pellets under 68.9 MPa. Complete combustion of the pellets was observed without the use of a combustion aid. The instrument was calibrated with benzoic acid as specified in the method. Benzoic acid was also evaluated as a sample and found to have a gross heat of combustion of 26.58 MJ kg^{-1}, which was similar to the literature value of 26.46 MJ kg^{-1} (Anon., 2010).

2.3. Plant experiments

Tomato (*Solanum lycopersicum* L. 'Red Robin') seeds were purchased from Tomato Growers Supply Company, Fort Myers, FL, USA. Marigold (*Tagetes erecta* L. 'Inca II Yellow Hybrid') seeds were purchased from Park Seed, Greenwood, SC, USA. Tomato and marigold seeds were planted in a starter mix (Sunshine® Seed Starter Mix, Sun-Gro Horticulture, Agawam, MA, USA) in cell plug trays in a growth chamber set at 25 °C, 16-h light/20 °C 8-h dark. After 24 days seedlings were transplanted into the experimental substrates. One hundred 90 mm pots (Kord Products, Inc., Brampton, ON, Canada) were filled with approximately 2.5 L each of the four substrate formulations and placed in a greenhouse maintained at 28 °C, 16-h day/20 °C, 8-h night utilizing both natural light and supplemental artificial lighting to maintain an average light intensity of approximately 600 μmol m^{-2} s^{-1}. Pots were spaced 25 cm apart (sufficient

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