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Research paper

An examination of physical and chemical properties of urban biochar for use as growing media substrate

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ABSTRACT

The purpose of this study was to evaluate the suitability and optimum rate of addition of Urban Biochar (UB) as an alternative to standard coir peat in plant growing media. UB was prepared through pyrolysis of 2:1 ratio of biosolids to greenwaste on a dry mass basis. Two incubation experiments are reported both with five different growing media mixtures which were subjected to periodic wetting and drying. Media mixtures consisted of different rates of UB (100%, 60%, 40%, 20%) mixed with composted pine bark on a volume basis and compared to an industry standard media with 0% UB. The physical and chemical properties of the mixtures were compared pre and post incubation. Substituting coir peat with UB increased media pH, C:N mass ratio, nutrient content, air filled porosity and bulk density. Furthermore, addition of UB to media also increased the proportion of particles in the desirable range for growing media (0.25–2 mm). UB amended mixes were found to be most stable in terms of both bulk density and resistance to particle breakdown. Fourier transform infrared spectroscopy analysis suggested that periodic wetting and drying enhanced surface oxidation. We found that UB amended substrates, up to 60% biochar on a volume basis, could deliver similar physical and chemical benefits to those of coir peat based industry standard media.

1. Introduction

Growing media are soilless substrates that provide plants with nutrients, air and water, and physical support [1]. Plant growing media must have well-balanced physical and chemical properties such as pH, EC, C:N mass ratio, bulk density (BD), air filled porosity (AFP), water holding capacity (WHC) and stability. In addition, the growing media must be free of pathogens and toxic chemicals [2]. Growers construct and formulate growing media from a range of substrates such as, pine bark, sphagnum peat, coir peat, compost, perlite and vermiculite [3]. Charcoal has been proved to be an effective substrate and has been used over many years in growing media [4]. In recent years, biochar has emerged as a potential growing media substrate as it resembles charcoal in terms of physical attributes although it is commercially manufactured under reduced oxygen at temperatures above 350 °C from a wider range of feedstocks. Most of the research on the use of biochar in growing media is aimed towards replacing environmentally unfriendly substrates such as peat, vermiculite and perlite from growing media with biochar [5–7]. These studies have shown that biochar improves BD, particle size distribution (PSD) and WHC of growing media. Biochar application to growing media has also known to improve retention of nutrients such as nitrogen and phosphorus [8,9]. Other advantages of using biochar in growing media include improvement of disease resistance [10,11], resistant to drought [12] and improvement of plant growth [13,14]. Furthermore, biochar properties vary depending on their production temperature and feedstock. For instance, biochar cation exchange capacity (CEC) may fluctuate from 0.03 to 0.67 mol kg^{-1}, pH may be between 5.8 and 10.9, surface area may range between 21 and 401 $m^2\ g^{-1}$ and C:N mass ratio may vary from 20 to 169 [15]. Hence, it is important to study the impact of particular biochars on vital physical and chemical parameters of growing media before recommending the biochar be used as growing media substrate. We are unaware of any studies of the use of high temperature biochar made from biosolids

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and greenwaste in growing media. Furthermore, it is unclear how the physical (WHC, pore size distribution, BD) and chemical properties (CEC, pH, EC, nutrient release) are influenced by the periodic wetting and drying that occurs in horticultural situations.

Pore size distribution is an important property of growing media as it governs retention and loss of water [2]. Pore size distribution is known to be highly affected by physical and chemical attributes of growing media such as: PSD, particle size arrangement, aggregate size, CEC, Ca and Mg content [16,17]. Wetting and drying cycles have also been identified as key factors for changes in pore size distribution of soil over time mainly by altering the arrangement of particle size and causing particle breakdown [18]. Similar pathways may exist in growing media causing changes to surface characteristics and physical integrity of biochar. Tian, Sun [5] measured the stability of biochar in media by performing particle size analysis at the start and end of media incubation and found that biochar improves media stability. They also found that the addition of biochar in the media increases the percentage of particles in the desirable range (0.25–2 mm) which is important for sufficient gaseous exchange and water retention. However, they measured physical breakdown without considering the effect of wetting and drying cycles on stability. As wetting and drying over a period of time may cause physical breakdown of biochar particles and also cause biochar surface chemical changes, it is clearly important to consider these effects on both physical and chemical stability of biochar.

Most of the high temperature biochar (>500 °C) has large surface area and high porosity [19] which gives it the potential to form aggregates with minerals and organic matter, ultimately leading to increased WHC [20,21]. Biochar (500 °C) has been shown to increase the WHC of soil [22,23] and in the case of growing media, Dumroese, Heiskanen [6] found 3:1 ratio of peat: biochar pellet on dry mass basis (500 °C) increased water availability and improved WHC. Pyrolysis temperature controls physical and chemical characteristics of biochar [24] with studies showing the highest increase in WHC by biochar produced from wide range of feedstock including manure and green waste (both hardwood and softwood) above 500 °C due to their higher microporosity and surface area [21,25,26]. Thus addition of high temperature greenwaste biochar to sand based growing media was able to hold and make water available to plants during dry periods [23,26,27].

Higher rates of biochar have proven to be more beneficial than lower rates for improving poor structured media [23,28]. For instance, adding 25% biochar to sand based media stored 260% more water when compared with 5% biochar [23]. In another study, 25% pelleted biochar mixed with peat on volume basis increased WHC of media [6].

Plant growth and dry biomass have been found to increase in biochar amended media as compared to unamended media [5,7,29]. This could be due to release of inherent nutrient present in biochar which becomes available to plants in the pore water. This inherent nutrient depends on the feedstock source, which may be released into the pore water [30]. In particular, phosphorus (P) release from biochar has been shown to be steady over time indicating that biochar may be a source of slow release P [30,31]. In an unfertilized, sand based media amended with biochar, concentrations of nutrient released from biochar to pore water (P and K) increased indicating the potential for nutrient release from biochar [23]. Similarly, increasing levels of Fe, K, Na, P, and B were found in press water extracts with increasing rate of biochar pellets resulting in increase of concentration of those ions in the media [6].

We present the results of two experiments in this paper which aim to investigate the potential use of UB as a plant growing media substrate by using UB at different rates and examine the effect of wetting and drying cycles on media physical and chemical properties. With respect to chemical properties, we attempt to understand nutrient release properties of UB amended growing media, in particular P. For physical properties we examined the effect of wetting and drying cycles on WHC and pore size distribution of biochar amended media. Furthermore, this study also investigates changes in physical stability of biochar amended media over time by looking at physical breakdown and bulk density changes. We hypothesize that UB possess physical and chemical properties suitable for plant growing media substrate due to its role in improving WHC of media, increasing nutrient availability in pore water and improving media stability.

2. Materials and methods

2.1. Formulation and characteristics of UB

2.1.1. Feedstock

Fresh biosolids were sourced from Bangholme Eastern Treatment Plant, Victoria. Moisture content of biosolids as received from the treatment plant was 72% as water mass fraction. Biosolids and greenwaste (mainly municipal softwood garden waste chopped to 1.5 cm) were dried in a commercial dryer to a water mass fraction of 21 (%) and blended at a ratio of 2:1 (on dry mass basis).

2.1.2. UB production

Feedstock was pyrolyzed in a commercial scale pyrolyzer by Pacific Pyrolysis Pty Ltd. at a high heat treatment of 650 °C with a residence time of 40 min. Feed rate was 125 kg h^{-1} with a biochar yield of 46% on a dry mass basis.

2.1.3. UB characterization

UB was characterized for its surface area and pore properties by using a Tristar 3000 surface area and porosity analyser (Micrometrics Instrument Corporation, USA) in degassed samples (250 °C for 18 h on a vacuum line) at −196 °C. The specific surface area of the sample was calculated by a standard multipoint Brunauer–Emmett–Teller (BET) method. Chemical properties were analysed by using Fourier transform infrared analysis (FTIR), and elemental analysis was done by ICP-OES after digestion. Some major properties of UB are listed in Table 1 and compared with other typical growing media constituents namely, pine bark and coir peat. Ultimate analysis of UB shows 74% carbon, 2.5% hydrogen, 0.7% nitrogen and 8% oxygen. UB has 14% volatile matter. UB has been characterized in detail by Kaudal et al. [19].

2.2. Media mixes

Five plant growing media (media mixes) were tested. Mix one (B0) consisted of, an industry standard, 20% coir peat and 80% composted pine bark on a volumetric basis. Composted pine bark (3–6 mm grade) was obtained from Debco Pty Ltd. Coir peat, which are residue from processing of coconut fibre, was sourced from Galuku Pty Ltd. Other mixes completely replaced coir peat with UB and progressively replaced composted pine bark as detailed in Table 2.

2.3. Media analysis

Media mixes were analysed both pre and post incubation. pH and EC of samples were measured by shaking 1 g of media in 20 cm^3 of deionized water on a reciprocating shaker at 50 Hz for 1.5 h [32]. CEC was measured according to the method of Rajkovich, Enders [29]. AFP and WHC were measured as per the Australian Standard for potting mixes (AS 3743). Mineral and metal analysis for Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, and Zn were performed using samples digested by a modified dry-ash method