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The effect of paper sludge and biochar addition on brown peat and coir based growing media properties

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ABSTRACT

Peatlands are crucial sinks for carbon in the terrestrial ecosystem, but they are jeopardized by their use as fuel or as growing media. Much research has been performed aiming to find high quality and low cost substrates from different organic wastes, such as coir, compost, sewage or paper sludges, and thus decrease peat consumption. The main objective of this work is to study the effect on peat and coir-based growing media of deinking sludge (*R*) and biochar obtained by pyrolysis of deinking sludge at 300 °C (B300). For this reason, mixtures of peat or coir with deinking sludge and corresponding biochar were prepared mixing them at 50/50 *v*/*v* ratios. The results showed that it is possible to improve the chemical and hydrophysical properties of peat and coir with addition of biochar and deinking sludge. Indeed, biochar increased air space, water holding capacity and total porosity of peat-based growing media whereas for coir, the best hydrophysical properties were obtained after deinking sludge addition. Finally, the use of biochar plus peat as growing media can increase lettuce yield by more than 100% with respect to peat growing media, which can be related with the improvement of hydrophysical growing media properties. This yield increment along with the reduction of the over-exploitation of peat can justify the use of biochar as growing media in spite of the cost associated to the pyrolysis process.

1. Introduction

Agricultural production through greenhouse cultivation is today, one of the most widely techniques used to increase agricultural yields due to the control of production factors such as watering, fertilizing, relative humidity, irradiance or the quality of growing media (Fei et al., 2008). Growing media or substrates include all materials that can be used to grow plants in a variety of production systems, such as greenhouse cultivation, containerised ornamental plant production, urban agriculture or green roof (Cao et al., 2014). Peat alone or blended with inorganic components such as vermiculite; perlite and sand (Bilderback et al., 2005) has been traditionally used as substrate material because of the excellent combination of peat properties such as low pH, high interchange cationic ability or adequate porosity (Robinson and Lamb, 1975). Peat is obtained from peatlands that cover an estimated area of 400 million ha, equivalent to 3% of the Earth's land surface. Most of them, approximately 350 million ha, are in the northern hemisphere, covering large areas in North America and Eurasia. Peatlands globally represent a major store of soil carbon, sink for carbon dioxide and source of atmospheric methane. Northern peatlands store around 450 billion metric tons of carbon, which is equivalent to approximately one third of the global soil carbon stock (Strack, 2008).

Peat is a non-renewable resource; that fact combined with increasing peat price have created a need for locating alternative growing media materials (Abad et al., 2001; Boldrin et al., 2010; Cleary et al., 2005; Holmes et al., 2000). A number of studies have shown that several organic residues such as urban solid wastes, plant wastes, sewage sludges, paper wastes, spent mushroom, coconut coir and even green wastes, after proper composting, can be used with variable results as growing media in lieu of peat (Abad et al., 2005; Chong, 2005; Garcia-Gomez et al., 2002; Maher et al., 2007; Méndez et al., 2011; Ostos et al., 2008).

Nowadays, the main attention has been focused on the potential biochar use in growing media formulation. Biochar is a solid carbon-rich material obtained from pyrolysis of biomass. Biochar production has attracted widespread attention as soil amendment

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(Enders et al., 2012; Lehmann and Joseph, 2009) and, only in recent years, as growing media component (Dumroese et al., 2011; Vaughn et al., 2015a,b; Zhang et al., 2014). Vaughn et al. (2015a) studied the use of biochar from several feedstocks as replacements for inorganic components such as vermiculite and perlite and digestate to replace organic components such as peat. They deduced that biochar can substitute peat in levels lower than 15% (*v*/*v*). Zhang et al. (2014) concluded that the highest quality growth medium and the highest quality ornamental plant growth was achieved mixing composted green waste with 30% of biochar and 0.7% of humic acids. Dumroese et al. (2011) found that pelletized biochar worked well when substituted for peat at a rate of 25% (*v*/*v*) but at higher levels lead to unsatisfactory results possibly due to high *C*/*N* ratios. Due to the small number of biochar types that have been considered as peat substitutes, there is a lack of information concerning their suitability for this use. Green wastes have been transformed into biochar in order to study their suitability for growing media (Tian et al., 2012). However, there is an imperative need to perform wider studies that take into account the intrinsic characteristics of the different biochars and the ratios the ratios of biochar to peat in order to produce good peat substitutes.

It is well known that properties depend greatly on the raw materials and pyrolysis conditions (Cantrell et al., 2012; Hossain et al., 2011; Masek et al., 2013; Méndez et al., 2013; Song and Guo, 2012). Temperature in one of the most significant parameters in the pyrolysis process of organic materials and consequently, it has a great influence on the chemical and physical properties of the biochar (Hossain et al., 2011; Masek et al., 2013; Méndez et al., 2013). Song and Guo (2012) studied the effect of pyrolysis temperature on poultry litter biochar and found that for agriculture use, the temperature of biochar production should be between 300 and 500 °C, whereas, for carbon sequestration and other environmental uses, temperatures higher than 500 °C were suggested. Yuan and Xu (2011) recommended the use of low temperature for the amendment of acid soils using biochar from crop residues. Taking into account the above mentioned considerations, the main objective of the present work is to study the performance of biochar from slow pyrolysis of deinking sludge at low temperature (300 °C) as component of peat and coir-based growing media for horticultural production.

2. Materials and methods

2.1. Selection and preparation of raw materials

The raw materials used in this study were deinking sludge (*R*), biochar obtained from deinking sludge pyrolysis at 300 °C (BR300), commercial brown peat (*T*) and coir (*C*). Biochar was prepared as follows: approximately 200 g of deinking sludge was placed in a covered steel cup and introduced in an electric furnace. The temperature was increased at 10 °C min^{-1} until 300 °C was reached and maintained for 2 h, leading to BR300.

2.2. Preparation of growing media

Mixtures of peat or coir with deinking sludge and corresponding biochar were prepared mixing them at 50/50 *v*/*v* ratios. Individual raw materials were used as control. Table 1 summarizes the formulation of the different growing media tested in the present work.

Table 1
Composition and formulation of different growing media.

Growing media	Components	Formulation (*v*/*v*)
T	Peat	100
C	Coir	100
R	Deinking sludge	100
BR300	Biochar from R at 300 °C	100
T–*R*	Peat/deinking sludge	50/50
T-BR300	Peat/biochar	50/50
C–*R*	Coir/deinking sludge	50/50
C-BR300	Coir/biochar	50/50

2.3. Chemical and physical properties of growing media

The growing media were characterized as follows:

pH and EC were determined in a ratio sample:water 1:10 (weight:volume) using a Crison micro-pH 2000 and a Crison 222 conductivimeter for pH and EC determination, respectively (Thomas, 1996; Rhoades, 1996).

Cation exchange capacity (CEC) was determined with $NH_4OAc/HOAc$ pH 7.0 (Sumner and Miller, 1996). Later, Na, K, Ca and Mg in the extract were determined with a PerkinElmer AAnalyst 400 Atomic Absorption Spectrophotometer. N Kjeldahl content was analyzed by the Kjeldahl method (Bremner, 1996).

Extractable P was determined by the Olsen method (Watanabe and Olsen, 1965). One gram of sample and 20 mL of 0.5 M sodium bicarbonate ($NaHCO_3$) solution were shaken for 30 min. Blue color in the filtered extract is developed with molybdate- ascorbic acid reagent and measured with a Shimadzu UV-1203 spectrophotometer at 430 nm.

Organic carbon was analyzed by the Walkley–Black method (Nelson and Sommers, 1996). Oxidizable matter in the sample is oxidized by 1N of $K_2Cr_2O_7$ solution. The reaction is assisted by the heat generated when 2 volumes of H_2SO_4 are mixed with 1 volume of $K_2Cr_2O_7$. The remaining dichromate is titrated with ferrous sulphate.

Proximate analysis of individual raw materials (*T*, *C*, *R* and BR300) was performed by heating samples in an electric furnace. First, weight loss at 105 °C during 24 h was used to calculate the moisture content; following, air treatment at 600 °C in a non-oxidizing atmosphere was used to measure the volatile matter. At this temperature sample was oxidized with air. The remaining weight is the ash content, whereas fixed carbon was calculated by difference.

Also, the hydrophysical properties of the different substrates were determined by using the following methodology: A container of known volume with a drainage hole sealed at the bottom was filled with the growing medium and slowly completely saturated by gradually pouring water onto the surface. Then, the container was placed over a watertight pan and the seal was removed from the container drain hole to allow all the free water to drain out of the container over 10 min. By recording the volume of water that drains, it is possible to determine the container volume filled with air, and hence air space. Afterwards, the entire content of saturated growing medium was weighted, placed in an aluminum pan, and completely dried in 105 °C oven for 24 h. By recording the weight of the media after removing from the oven we calculated the amount of water that is dried off the media, and therefore, the volume of water held by the media (water holding capacity). The total porosity was calculated as the addition of the air space and the water holding capacity. Although there are no universal standards for substrate physical properties, there are ranges in which most potting substrates utilized in the commercial production of horticultural crops fall such as container capacity from 45 to 65%, air space from 10 to 30% (Yeager et al., 1997) and total porosity values from 50 to 85%. The bulk density of an ideal substrate should be lower than 0.40 g cm^{-3} (Abad et al., 2005). Table 2 shows acceptable range of some physical and chemical properties for container media.

Particle size distribution of the raw materials was determined by passing 50 g of dried samples through a nest of sieves (2.0 mm, 1.0 mm and 0.5 mm mesh). The material retained on each sieve