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Research article

Chemical characterization of biochar and assessment of the nutrient dynamics by means of preliminary plant growth tests

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ABSTRACT

Biochar can be produced from several organic sources with varying nutrients and metal concentrations. Four commercial grade biochars were evaluated as peat substitute. Biochars were characterised for plant nutrients and for biological stability. The results showed that there were negligible quantities of N and P and generally high levels of K and high biological stability. When these materials were mixed with peat at 10, 25 and 50% and nutrients were added to bring them to the same level of nutrients as in fertilized peat, it was found that biochar mixtures considerably reduced the levels of calcium chloride/DTPA (CAT) extractable N (including nitrate), P, and electrical conductivity– greater extent with higher rates of biochar addition except for K. The pH and K levels were increased with biochar addition. The drop in EC has important implications regarding the use of other materials used to dilute peat, for example, composted green waste, the rate of dilution is limited due to high EC and biochar addition gives the potential for higher peat dilution of these materials. Nitrate and phosphorus are very vulnerable to leaching of these nutrients in the environment in peat substrates and the binding of these by biochar has implication for leaching and nutrient application strategy. Root development using Cress test and tomato plant height and biomass using containers, were in some cases better than peat indicating that biochar could be used to dilute peat e.g. for seedling production where root development and rapid growth are very important. Application of biochars resulted in a marked reduction of N (and P) in the plant. There were significant correlation between CAT extractable N and P and corresponding plant concentration, indicating the standard growing media test, CAT, would be suitable for assessing the nutrient status of peat biochar mixes.

1. Introduction

Biochar is the product of pyrolysis whereby organic material either of plant or animal origin are treated to >250 °C (usually 450–600 °C) in a no or low oxygen environment (Solaiman et al., 2012). The quality (in particular surface chemical characteristics and pore size) of the biochar produced depend on production factors [such as temperature, feedstock and residence time (Gaskin et al., 2008)]. Biochar products have progressively been receiving increasing attention and uses as biomass. This is due to several factors, such as it is one of the very few technologies that can actively remove carbon (C) from the atmosphere, and it is suitable for a range of environmental, agricultural and horticultural applications (Dumroese et al., 2011; Shackley et al., 2016). Thus, biochar has attracted widespread interest as a growth medium amendment that enhances cation exchange capacity (CEC), nutrient and water retention, and that neutralizes acidity (Karami et al., 2011; Sun et al., 2012). Biochar has potential to sequester carbon in soils and simultaneously improve soil quality and plant growth, therefore it is an option for climate change mitigation *via* C sequestration and promotion of resource efficiency (Windeatt et al., 2014; Brassard et al., 2016). Biochar is energy self-sufficient and/or energy positive for getting syngas and biofuel (Irfan et al., 2016). Moreover, biochar has been successfully produced from among other things by municipal waste e.g. garden and park waste, agricultural wastes e.g. straw, food waste, digestate, and even sewage sludge (Shackley et al., 2016). Additionally, biochar can significantly

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enhance soil capacities to absorb and immobilize heavy metals such as Cd, with considerable environmental protection (Zhao et al., 2016).

Peatlands are valuable habitats and may provide environmental services such as biodiversity, regulation of the local water quality and local hydrology conditions including flood protection. They are also considered important C sinks, but as soon as a peatland is drained, aerated, limed and fertilized or when its peat is extracted, its organic matter decomposes quickly and turns into a source of greenhouse gases. Peat is the principal material for growing media in Europe and peat production in Europe is more than 40 million m^3. Almost all the peat is produced in northern Europe and is transported long distances e.g. Cyprus leaving an additional large carbon footprint. Peat is a standard by which other growing media is compared. Biochar probably has the potential for reducing peat usage/replacement and affecting positive plant yield. Although a mean yield increase of 10% has been reported, averaging different crops, soils and climates (Jeffery et al., 2011) it is also well known that "all biochars are not created equal" (Amonette et al., 2009) and as a consequence the effects on crops are both biochar specific and site specific (Mukherjee and Lal, 2014). In order to better understand this complexity, more studies are required before introducing the biochars strategy among the common agricultural practices (Lorenz and Lal, 2014), particularly its use as a peat replacement. Most of the studies relate to biochars application in soil *in situ*. There is limited published information on the use of biochars as peat replacement (Graber et al., 2010; Dumroese et al., 2011; Tian et al., 2012; Méndez et al., 2015) and some of the work that has been carried out has been done on an *ad hoc* basis. In addition, Dumroese et al. (2011) used pelletized biochar which in our view would make biochar totally uneconomical to replace peat, and this factor need to be considered as well. Sohi et al. (2013) conclude that biochar can partially replace peat as growing media, but the cost of production from most feedstocks would make it prohibitive unless a high gate fee was available. Some of the characteristics that are important for use as peat replacement are not too high pH, low electrical conductivity (EC), high surface area, low in heavy metals and polycyclic aromatic hydrocarbons (PAH) contents. Measurement of C, H and O_2 and their ratios may also be important as an indicator of stability. There is also lack of information on biochar characterization either on its own or when mixed with peat using tests developed specifically for growing media e.g. peat, compost. Recently European Committee for Standardization (Comité Européen de Normalisation- *CEN*) has developed test methods specifically for growing media. Information on the performance and changes in nutrient in peat biochar mixes using *CEN* tests is almost non-existent.

The objective of the current study was a) to characterize the biochar materials, b) to evaluate the effect of biochar addition in peat on extractable nutrient content and on nutrient dynamics over a short period, c) to evaluate four biochars produced commercially in Europe as a peat diluent (growing medium) as evidenced by plant growth e.g. germination and root development and short term plant growth, d) to evaluate the effects of biochar addition in peat on plant nutrient content and finally e) evaluate if the *CEN* tests for growing media (peat, compost etc.) are suitable for peat/biochar mixtures. No attempt was made here to look at the physical effect of biochar on peat.

2. Material and methods

2.1. Biochars material

The current study took place at Bord na Mona, Ireland. Four commercial grade biochars, two from Switzerland (A and B) and two from Germany (C and D) were used in these trials. The four biochars had the following feedstocks: A = woodchips, B = husks and paper fibre wood screenings from tree branches, C = forest wood, beech, spruce, ash etc. and D = wood screenings from tree branches. Three of the biochars were produced using the Pyreg equipment and one using Schotteredorf process. Temperatures were between 450 and 600 °C. However exact information of their production details are not known due to commercial sensitivity. A good quality professional grade H_4-H_5 on von Post scale peat was used as a control and as primary material to which the biochar was added. The four biochar materials were assessed for basic characteristics (Table 1), as for pH (EN 13037, 2002), EC [in water extract at 1:5 (v:v) ratio, EN 13038, 2002] and calcium chloride/DTPA (CAT) extractable (1:5 v:v), NH_4-N, NO_3-N, total extractable N (NH_4-N+NO_3-N), P, K (EN 13651, 2002) and Oxygen Uptake Rate (OUR) (EN 16087-1, 2011). Particle size fractions (%) of all biochars were done by using a stack of sieves (Table 1).

2.2. Preparation of growing media

The examined biochars diluted in different ratio into the peat. Therefore, the four biochars were added at the rates of 10%, 25% and 50% to the peat resulting to 13 mixtures (treatments) including control treatment of pure peat. Then mixtures were brought to N, P and K levels to 170 mg N/L as ammonium nitrate, 70 mg P/L as triple superphosphate and 100 mg K/L as potassium sulphate respectively of peat biochar mixtures and of limed peat by dolomitic lime (4 g/L). Account was taken of the CAT extractable N, P and K that came from the biochars and fertilizer levels were adjusted accordingly. In most cases there were almost negligible amount of N, some P and excess of K. Where K was in excess, no K was added into the mixture.

2.3. Experimental setup

In the first experiment the moistened samples at around 60% moisture was left for a week and a subsample was taken to analyse for pH, Electrical conductivity, NH_4-N, NO_3-N, P and K using the CAT extraction *EN* 13651 and Lachat autoanalyzer. Subsamples were taken again at 6 and 14 weeks in order to study the dynamics of the above mentioned variables through time. Samples were also analysed for phytotoxicity using the *EN*16089 method. In more details, 10 replicates for each examined biochar mixture were evaluated through Cress Test. A three day germination test with 30 cress seeds (*Lepidium sativum*) performed in a square Petri dishes at 28–30 °C in darkness in the lab. Germination rate (in %) and root length (in mm) were measured in this test.

In the second experiment, growing trials were carried out in a heated glasshouse in plastic trays and pots. Therefore, in the first trial, the examined media were filled up in plastic seedling trays and 10 tomato (*Solanum lycopersicum* Mill.) and 10 petunia (*Petunia hybrida* L.) seeds were sown in 10 modules (1.5 cm × 1.5 cm) (one seed per module) for each media on 28th August. The petunia trials took place once for seed emergence while the tomato trials were conducted twice and seedling were grown for 4 ½ weeks and 5 ½ weeks respectively, and plant height was measured after 1 week and at the end of each trial.

In the second trial, the same materials were used and treatments were similar as in the first experiment, but substrate were analysed only at week one for pH, EC, NH_4-N, NO_3-N, P and K using the CAT extraction. Growing trials were carried out in a heated glasshouse and seedlings were grown in pots (10 cm) with 3 replicates for each of the examined media. Seedling fresh and dry weights were measured after about 5 weeks of growth. Plant mineral analysis was carried out on the whole tomato plants (three

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