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Biochar as growing media additive and peat substitute

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Abstract

Environmental concerns raised the demand for alternative growing media substituting sphagnum peat. However growing media formulations still depend on peat and alternatives are limited. Biochar is carbonized plant material and could be an appropriate additive or even substitute for sphagnum peat. Freshly produced, it is free from pathogens, has a low nutrient content (if produced from nutrient poor feedstock), a very high structural stability and likely other favourable properties such as air capacity and water holding capacity.

Preliminary tests were conducted to compare biochar with other growing media and growing media additives. The growth of a miniature sunflower, pH and electrical conductivity (EC) was measured in different growing media such as biochar, perlite, clay granules, sphagnum peat and peat mixed with biochar in the ratios 1 : 4, 1 : 1 and 4 : 1 (25, 50 and 75 %, by volume).

Fresh biochar has a similar EC than peat which is even lower after rinsing with water. Due to the relatively high pH of biochar, it could be added to peat instead of lime in a concentration of up to 75 %. The growth of the sunflower was similar in all growing media. Only the plant weight was slightly higher of plants that grew in perlite or peat. There is a large potential for optimization such as selection of particle size and feedstock for biochar production and growing media formulations for specific plant requirements.

1 Introduction

Worldwide approximately 11 million metric tons of sphagnum peat are used for horticultural purposes per year (Apodaca, 2013). Although there are efforts to develop alternative growing media, peat remains to be by far the most important substrate and frequently the sole ingredient of growing media formulations. Peat is still available in large quantities and modern horticulture depends on quality-assured growing media. The favourable characteristics of horticultural peat are its large water holding capacity

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(WHC), its high air capacity at 100 % WHC, the homogeneity and availability of the product, the absence of weed seeds and pathogens, its low bulk density, low pH, low microbiological activity, low nutrient contents, and its low salt content (Reinhofer et al., 2004; Schmilewski, 2008; Michel, 2010). The low pH and nutrient content is desired as it facilitates to adjust the media to meet the plant specific requirements by liming and fertilizing.

However the environmental concerns are rising as peat bogs are valuable habitats, important carbon (C) stocks and they provide environmental services such as regulation of the local water quality and water regime or flood protection (Alexander et al., 2008). Peat and the C contained in it is protected from mineralization by its anoxic and acidic environment. As long as peat remains in its natural and undisturbed habitat its mineralization is very slow and peat lands are therefore mostly natural C sinks. However it decomposes quickly and becomes a source of greenhouse gases (GHG) once the peat land is drained, extracted, aerated, limed and fertilized (Cleary et al., 2005). Therefore the conservation of peat lands gained importance in recent years and it is likely that peat use in growing media is further restricted (Rivière and Caron, 2001).

However most alternatives are still inconsistent, have a low structural stability and cause nitrogen (N) immobilization, contain too many nutrients (e.g. compost) or have a low water holding capacity (Reinhofer et al., 2004). The search for substitutes remains as long as there is no material suitable to substitute peat entirely (Reinhofer et al., 2004; Schmilewski, 2008; Michel, 2010).

Biochars produced from nutrient poor feedstock such as wood have low nutrient contents (Gaskin et al., 2008) and have an exceptional structural stability (Tian et al., 2012) and are extremely recalcitrant against microbial decay (Kuzyakov et al., 2009). Therefore wood biochar produced at elevated temperature is unlikely to induce N immobilization, is free from seeds and pathogens and would not provide significant amounts of nutrients. However biochar has mainly been researched as a soil improver in relatively low concentrations. Little information is available on its performance as an additive or even substitute for peat. Therefore this trial aimed to test biochar as growing media

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and we hypothesized that biochar performs as good as other growing media with similar physical characteristics.

2 Materials and methods

2.1 Biochar properties

BlackCarbon A/S in Denmark produces biochar from crushed wooden boxes in continuous flow with combined heat and power production. Approximately 25 kg of biochar is produced per hour. The biomass was heated to a maximum temperature of 600 °C, the producer gas had a temperature of 460 °C and the mean residence time of the feedstock was one hour. This feedstock is free from bark and has minimal ash content. The resulting biochar seems to be appropriate to be used as peat substitute, with an average carbon content of 85 % and a very low ash (1.8 %) and nutrient content. Therefore the electrical conductivity (EC) of the freshly produced biochar is low (612 $\mu S\,cm^{-1}$) in comparison to other biochars (e.g straw biochar > 16 $mS\,cm^{-1}$). This biochar was used for simple growing experiments without modification or post-treatment. The particle sizes ranged from 5 to 30 mm and the airspace of the media is therefore relatively large.

2.2 Sunflower growing trials

The growth of a mini sunflower (*Helianthus annuus*, Teddy Bear) in biochar was compared with other similar growing media and growing media additives such as perlite, clay granules, and peat. Three seeds were directly planted in the growing media and the plants were reduced to one plant per pot three weeks after planting. In order to avoid any growth limitations by nutrient deficiencies the media were fertilized with a slow release conventional fertilizer (Osmocote, 17-9-11,-2 NPK, Mg + TE, Scotts Celaflor GmbH & Co. KG, 20 mL per liter of substrate). Water stress was avoided by daily irrigation. The applied water was dosed with a beaker, and all treatments received

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equal amounts of irrigation water. The peat was used limed (20 mL per L substrate) or without liming. Biochar was used as produced or with reduced pH by adding 20 mL of leonardite (humic and fulvic acids, Humintech GmbH, Düsseldorf, Germany) per liter of substrate. Clay granules (Seramis®, Mars GmbH, Mogendorf, Germany) is a clay granulate used as growing media. This product is sold with specific fertilizer formulations. In order to compare biochar with clay granules and perlite, the Seramis fertilizer was used for all growing media as recommended. The plants were grown in one liter pots and arranged in a Latin square (4 treatments and 4 replicates).

The peat experiment was arranged in a randomized complete block design with 4 replicates. The treatments were 0 %, 25 %, 50 %, 75 % and 100 % (by volume) biochar and peat respectively.

2.3 EC and pH of the growing media

The biochar, peat, coco coir and the different mixtures (25, 50 and 75 %, by volume) were measured with 3 replicates. EC was measured using the PCE-CM 41(PCE Deutschland GmbH, Germany) conductivity meter and for pH measurements the pH-Meter PCE-PH20S was used. This pH-meter has been developed for directly determining the pH value of soil. The biochar substrate consists of stiff pieces and coarse air-filled pores. Therefore an extraction was necessary.

A combination of the saturated media extraction and the pour-through method was used for EC and pH measurements. Plastic (PP) cups with a volume of 350 mL were perforated at the bottom and filled with substrate. These cups were stacked into 350 mL cups without perforation and filled with distilled water. After approximately 3 h the perforated cup was lifted and the water trained into the second non-perforated cup. The collected water was used to measure EC and pH.

The pur-through method was used or pH and EC readings if the fertilized media was measured during the sunflower growth trials six weeks after planting. The media was wetted until just saturated and left to stand for about two hours. Then, a volume

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of water sufficient to produce enough leachate for EC and pH measurement (100 mL) was applied to the pot. EC and pH was measured in the collected leachate.

To assess the maximum water holding capacity and drying characteristics, the medias clay granules, biochar, peat and a 1 : 1 biochar-peat mixture (by volume) was soaked in water for 24 h, than trained and left for drying. The weight loss of the 350 mL cups was recorded regularly.

2.4 Statistics

Plots were made with SigmaPlot 12. Homogeneity of variances, one-way ANOVA and LSD post hoc tests were performed with IBM SPSS Statistics, version 20.

3 Results and discussion

3.1 EC and pH

Due to a high pH of the biochar (pH 9) it served as a substitute for lime. Biochar peat blends can contain up to 80 % biochar without raising the pH above 7 (Fig. 1).

The initial EC of biochar (612 $\mu S\,cm^{-1}$) was similar to that of the unfertilized peat (633 $\mu S\,cm^{-1}$) and was reduced to 380 $\mu S\,cm^{-1}$ and 415 $\mu S\,cm^{-1}$ respectively, after rinsing with distilled water. Biochar which was used for two month as growing substrate had an average EC of 360 $\mu S\,cm^{-1}$. The EC of both, the pure biochar as well as the pure peat was approximately 1/3 higher than that of the mixtures (25, 50 and 75 %) before (470, 446, 352 $\mu S\,cm^{-1}$) and after rinsing (236, 253 and 229 $\mu S\,cm^{-1}$) with distilled water. Adding 10 % leonardite reduced the pH of pure biochar to 5.2 but increased the EC up to 3 $mS\,cm^{-1}$. A 5 % leaonardite addition is sufficient to reduce the pH below 7, but increases the EC to 1.5 $mS\,cm^{-1}$. The water retention of the biochar was similar to that of the clay granules. If the biochar was mixed with peat (1 : 1 by volume, Fig. 2) it did not change the water uptake and drying characteristics, compared to the peat without biochar addition.

Six weeks after planting the growing media clay granules, biochar, biochar + HA and perlite had the same pH and EC (means, 7.7 and 827 $\mu S\,cm^{-1}$, respectively). The HA had no lasting effect on pH and EC. The growing media with peat and biochar had significantly different pH values. Liming increased the pH significantly. Surprisingly, biochar reduced (25 % addition) and increased the pH in mixtures with peat at higher concentration compared to peat. The media with 25 % biochar addition had a significantly lower pH than peat, a 50 % addition did not influence the pH significantly in comparison the pure peat and a 75 % addition increased the pH significantly (Fig. 3). The EC increased significantly if the peat was limed or amended with 25 % biochar, but was lower in the 50 %, 75 % mixtures and pure biochar treatments (Fig. 3b).

3.2 Sunflower growing performance

The average plant height at harvest did not differ significantly between the treatments (43, 44.5, 43.4, 45.6 cm for clay granules, biochar, biochar + HA and perlite respectively). However the mean fresh weight of plants growing in perlite was significantly higher ($p < 0.05$, 92.3 g) followed by clay granules (81.7 g) biochar (76.6 g) and biochar + HA (69.2 g). Acidification with HA did not improve plant growth.

The plants growing in peat and biochar-peat mixtures had the same size. Only the weight of the plants differed significantly (Fig. 5). The heaviest plants grew in limed peat followed by peat without lime. However the difference was small and the weight of plants growing in media with 75 % biochar addition was not significantly reduced and that with a 25 % biochar addition was not significantly different from plants grown in peat without lime.

Considering that biochar was used without modification in relatively coarse pices, biochar performed remarkable well as growing media. Particle size and type of biochar is most likely influencing the physical characteristics of the media and there is considerable scope for optimization.

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3.3 Avoided GHG emissions due to substitution of peat with biochar

The decay of biochar is extremely slow (Kuzyakov et al., 2009). Therefore carbonization decelerates the C cycle and sequesters C for relatively long periods of time. In addition C emissions associated with the decay of peat would be avoided if biochar replaces peat. Furthermore the pyrolysis process to produce biochar could provide renewable energy (for instance to heat greenhouses) substituting fossil fuels. However, the emissions from the decay of horticultural peat is only assessed in the UK (Barthelmes et al., 2009).

The potential for emissions reductions from substituting fossil fuels depends on the type of fuel replaced and on the pyrolysis technology used. The average C content of the biochar used in these trials is 85 % and has an estimated labile carbon content of 10 %. Consequently one metric ton would sequester approximately 2.8 Mg of CO_{2e}.

Processing and transport of both biochar and peat requires fossil fuel based energy. Transport pathways are most likely shorter for biochar, in particular when the production unit resides with the feedstock source and consumption site. Therefore, for simplicity, only the carbon contained in peat and released as CO_2 during its decay is used for this calculation. One Mg of peat contains approximately 500 kg of carbon corresponding to 1.7 Mg of CO_{2e} after its decay. The IPCC's 100 year time horizon is the standard reporting time frame and assumes that all organic material will decompose within 100 years (IPCC, 2006). Peat and other growing media are used in volume rather than dry weight. The biochar produced from pine chips had a bulk density of 0.15 $g\,cm^{-3}$, i.e. it can be very similar to that of peat substrates (Pindstrup Mosebrug A/S, personal communication, 2012). Under this assumption, the replacement of peat with biochar could avoid 4.5 $Mg\,CO_{2e}\,Mg^{-1}$ of peat substituted.

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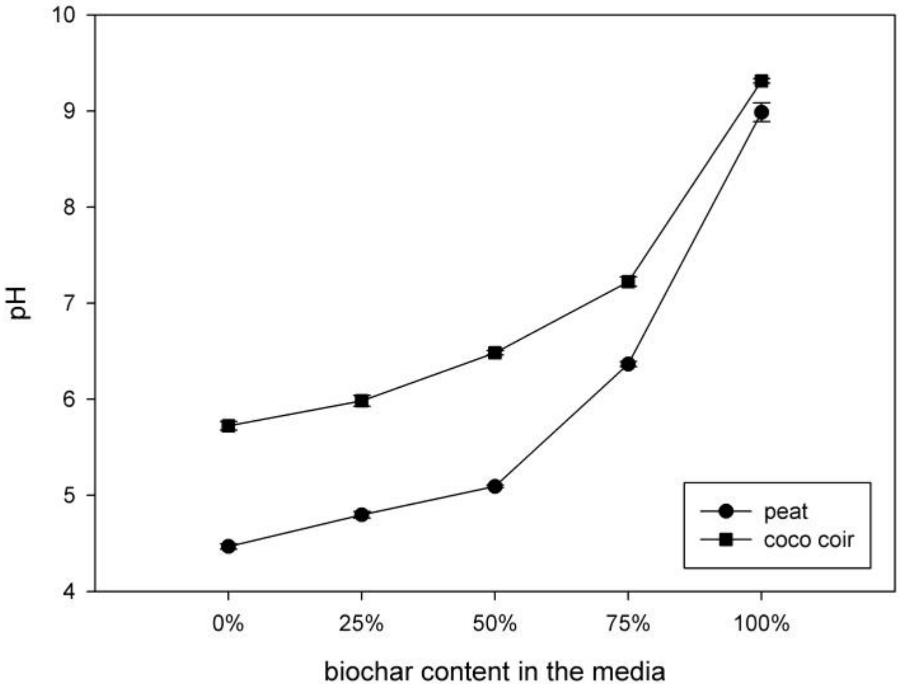

Figure 1. Changes in pH with increasing rates of biochar added to peat or coconut coir ($n = 3$, error bars = standard deviation).

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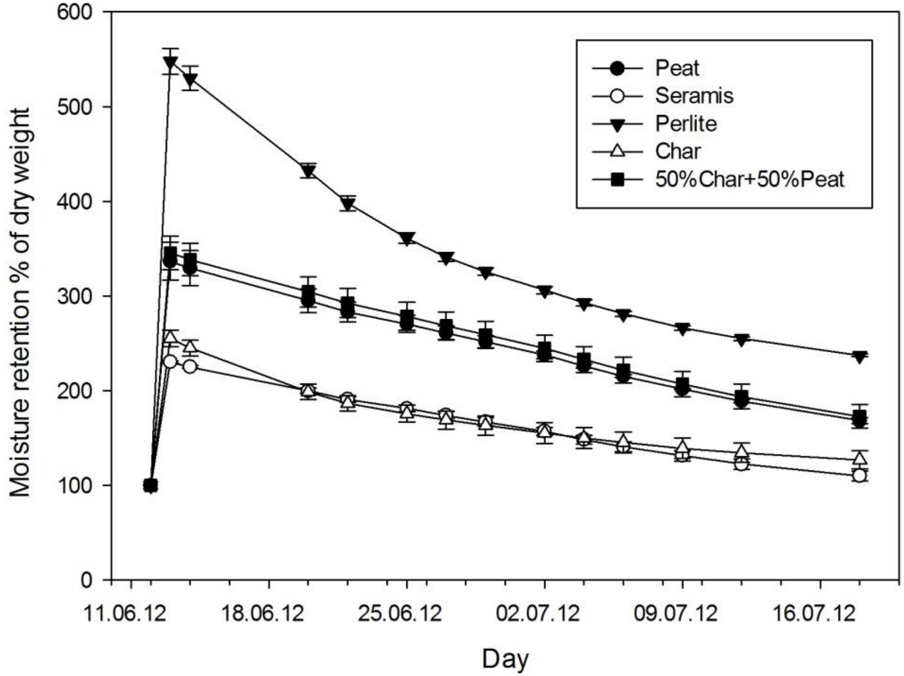

Figure 2. Moisture uptake and drying of different growing media (peat, clay granules, perlite, biochar, and biochar mixed with peat, $n = 3$, error bars = standard deviation).

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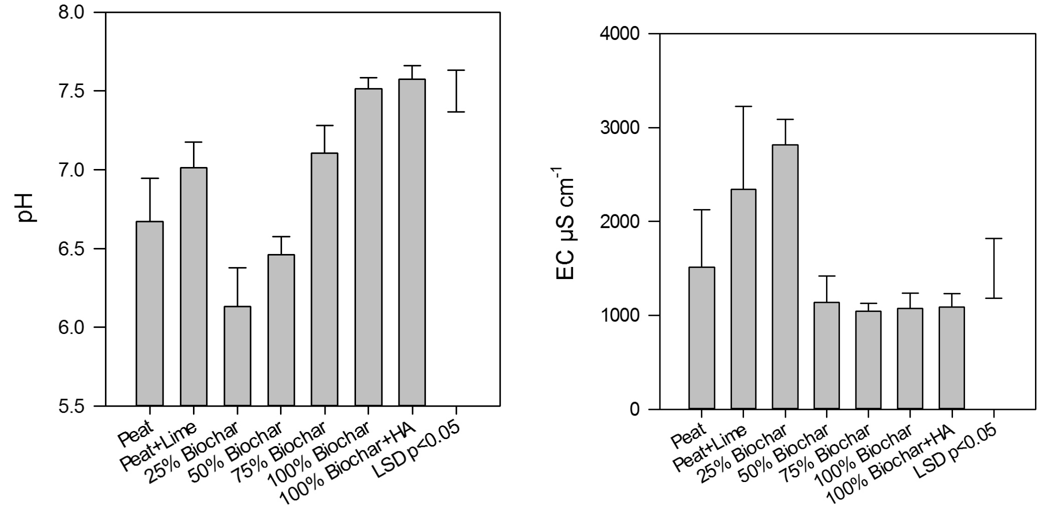

Figure 3. pH (left) and EC (right) of peat, limed peat, biochar and biochar-peat mixtures in leachate 6 weeks after planting ($n = 4$, means and standard deviation, HA = humid acid, Leonardite, LSD = least significant difference).

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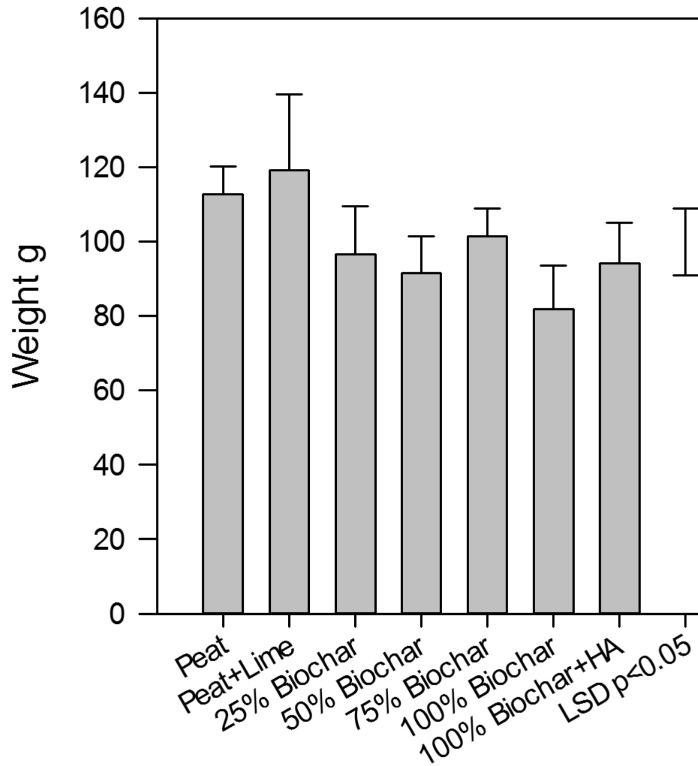

Figure 4. Fresh weight of miniature sunflowers grown in peat, limed peat, biochar and biochar-peat mixtures ($n = 4$, means and standard deviation, HA = humid acid, Leonardite, LSD = least significant difference).

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