Growth of Norway spruce seedlings after transplanting into silty soil amended with biochar: a bioassay in a growth chamber – Short Communication

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ABSTRACT: Biochar (BC), the carbon-rich by-product resulting from pyrolysis of biomass, is used for bioenergy and increasingly as a soil additive for carbon sequestration and soil improvement. However, information about the effects of BC on forest productivity and reforestation success, especially on boreal and temperate forest soils, is scant. We examined the effects of two BC types (Canadian and Finnish) added in proportions up to 60 vol.% into a common alluvial silty soil on the growth of transplanted Norway spruce (*Picea abies* [L.] Karst.) seedlings in a growth chamber. We found no marked differences in seedling growth among the binary growing media mixes used. Seedling growth attributes (seedling height, terminal shoot growth, root volume) differed consistently only between the BC types in the highest proportion used. The terminal shoot growth differed overall among the two BC types. These results suggest that BC may be applied into mineral soils without detrimental chemical effects on tree plantation success. Our results provide foundation for further field research on the longer-term impacts of adding BCs to boreal forest soils.

Keywords: carbon sequestration; forest soils; soil additives; outplanting success; pyrolysis

Biochar (BC) is the carbon-rich by-product from anaerobic pyrolysis of biomass that commonly originates from agriculture and forestry. Although BC is used as bioenergy, interest is increasing to use BC as a soil additive (Laird 2008; Blackwell et al. 2009; Mcelligott et al. 2011) to sequester carbon and improve soil quality, mainly on agricultural soils and especially in tropical environments (Atkinson et al. 2010; Major et al. 2010; Vaccari et al. 2011).

BC applications into mineral soils effectively sequester carbon as the recalcitrant nature of BC reduces the release of carbon to the atmosphere (Verheijen et al. 2009; Shackley et al. 2010). Furthermore, these applications can increase soil surface area and porosity and lower bulk density, thus potentially improving water retention capacity, nutrient availability, and microbial activity (Chan et al. 2008; Blackwell et al. 2009; Brockhoff et al. 2010; Mcelligott et al. 2011).

Recent results from US temperate forests suggest that pyrolyzed BC can be returned to forest sites to increase soil nutrient and carbon stocks with little effect on short-term tree growth (Mcelligot 2011). However, practically no information is available about boreal forests; some work with wood ash as a nitrogen-free fertilizer to counteract the loss of nutrients resulting from tree harvesting and soil acidification has been reported (Saarsalmi et al. 2004; Augusto et al. 2008). Fire-produced charcoal usually has no harmful effect on boreal forest productivity although it can affect the growth of tree seedlings and other vegetation (Wardle et al. 1998).

Therefore, our objective was to examine effects of two BC types, a Canadian powder from agriculture and forestry residues and a coarser Finnish BC from softwood chips, added to a common alluvial silty soil in proportions up to 60 vol.% on the growth of transplanted Norway spruce (*Picea abies* [L.] Karst.) seedlings in a growth chamber.

MATERIALS AND METHODS

Seedlings of a local seed source were grown operationally in a forest nursery in Suonenjoki, Finland (62°64'N, 27°05'E), stored at –3°C from autumn until January, and thawed at 6°C for three days following standard procedures (Heiskanen 2013). After thawing, roots were washed clean with tap water. Root volume was determined using water displacement (Harrington et al. 1994). Mean seedling height and root volume were 19.6 cm and 1.54 cm^3 (SD 0.35 and 0.33).

Seedlings were transplanted into separate 0.5 l plastic pots (Teku, MQC 9 × 9 × 9.5 cm, Pöppelmann GmbH & Co. KG, Lohne, Germany), which were filled with growing media by hand. The growing media were based on a commercially produced Finnish wood BC (Preseco Oy, Espoo, Finland) originating from partially debarked Norway spruce and Scots pine (*Pinus sylvestris* L.) chips (FBC, pre-sieved to < 2 mm in particle size) or a commercially produced Canadian BC powder (Dynamotive Energy Systems Corporation, Richmond, Canada) originating from agricultural or forestry biomass (CBC), which were mixed into alluvial silty soil in volume proportions 0, 15, 30, 45 and 60%. Silty soil was used because of its homogeneity. Ten pots were filled with each medium, resulting in a total of 100 transplanted seedlings (2 BC types × 5 media × 10 replicates).

Total (from closed wet HNO_3-HCl extract) and soluble exchangeable [cations and P from acid ammonium acetate (pH 4.65) extract and N from KCl-extract] concentrations of macronutrients (N, P, K, Ca) and boron (B) as well as physical soil properties (bulk and particle densities, total and air-filled porosities, water retention) were measured for the growing media or their components using standard analyses described in Dumroese et al. (2011) (Tables 1 and 2). Media components were measured for particle-size distribution by dry sieving (Fig. 1). The CBC was the same as that described by Dumroese et al. (2011). FBC was of coarser texture than CBC (for more FBC details Tammeorg et al. 2012). pH from 1:5 soil:water suspension was 6.2, 6.8 and 7.7 for CBC, FBC and silt, respectively.

Transplanted seedlings were grown in a growth chamber (Type 10' Sp/5 DU-Pi, Weiss Klimatechnik GmbH, Reiskirchen-Lindenstruth, Germany). Diurnal light cycle was set to no light 4 h, dim 1 h, full light 18 h, and dim 1 h. Full light yielded photosynthetically active radiation at the seedling shoot

Table 1. Basic physical properties for the growing media used (*n* = 3 samples)

Property		Silt	Finnish biochar (FBC)					Canadian biochar (CBC)				
			FBC15	FBC30	FBC45	FBC60	FBC100	CBC15	CBC30	CBC45	CBC60	CBC100
Bulk density	($Mg·m^{-3}$)	1.48	1.42	1.21	1.05	0.86	0.20	1.39	1.20	1.03	0.88	0.37
Particle density	($Mg·m^{-3}$)	2.65	2.63	2.58	2.55	2.50	2.19	2.61	2.55	2.51	2.47	2.23
Loss on ignition (%)		0.40	2.20	5.7	8.40	13.0	40.30	3.80	9.00	12.40	15.60	36.5
Total porosity (vol. %)		44.2	45.8	53.2	59.0	65.6	90.60	46.70	52.80	58.90	64.60	83.6

Table 2. Total nutrient concentrations and C/N ratio as well as soluble exchangeable nutrient concentrations and effective cation exchangeable and base saturation percentage (BS) after one-day moist incubation for the growing media components used (one combined sample)

Component	Total nutrients						Soluble nutrients (after one-day moist incubation)								
	N	P	K	Ca	B	C/N	NH_4	NO_3	N_{tot}	P	K	Ca	B	BS (%)	ECEC* ($cmol·kg^{-1}$)
	($mg·kg^{-1}$)														
Silt	206	513	1,300	2,090	< 0.40	< 2.4	0.57	0.86	2.0	4.1	13	73	< 0.014	> 68	< 0.8
FBC	6,100	318	2,340	3,880	5.8	145	< 1.02	0.46	6.5	87	969	2,080	3.8	> 95	< 4.8
CBC	3,310	157	4,700	4,760	16.0	212	1.03	1.3	6.3	28	2,530	1,440	9.4	> 97	< 8.8

*exchangeable acidity proportion of ECEC was < 0.25 $cmol·kg^{-1}$ for all cases

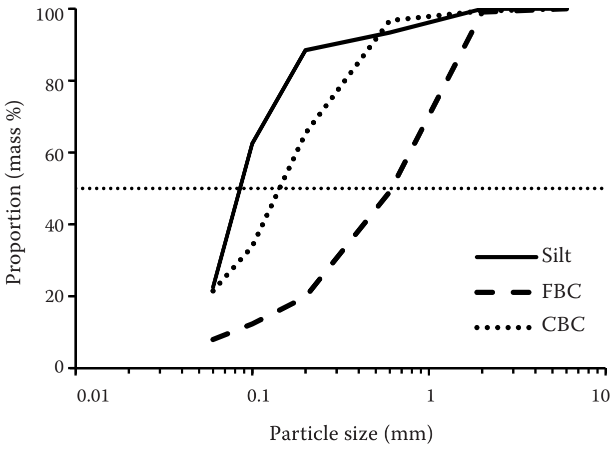

Fig. 1. Particle size for the studied media components expressed as the percentage passing sieve sizes; horizontal line denotes the 50% proportion

level of 335 μE $m^{-2} \cdot s^{-1}$. Temperature was 19.5°C (day) and 12°C (night). Relative humidity varied between 30 and 60%, and was about 10 percentage points higher with no light.

The target volumetric water content was aimed to equal half the total porosity, a level considered to yield sufficient water and oxygen availability (Wall, Heiskanen 2003). Pots were watered manually 2–3 times per week using tap water to their target gravimetric masses. The resulting mean water content was relatively uniform (39–42% of total porosity) in each growing medium during the growing experiment (Fig. 2) and subsequently air-filled porosity was sufficient (Wall, Heiskanen 2003; Heiskanen 2013).

Electrical conductivity was measured from additional seedling pots (3 per growing media mix) using a 5TE sensor and ProCheck hand meter (Decagon Devices Inc., Pullman, USA). Electrical conductivity

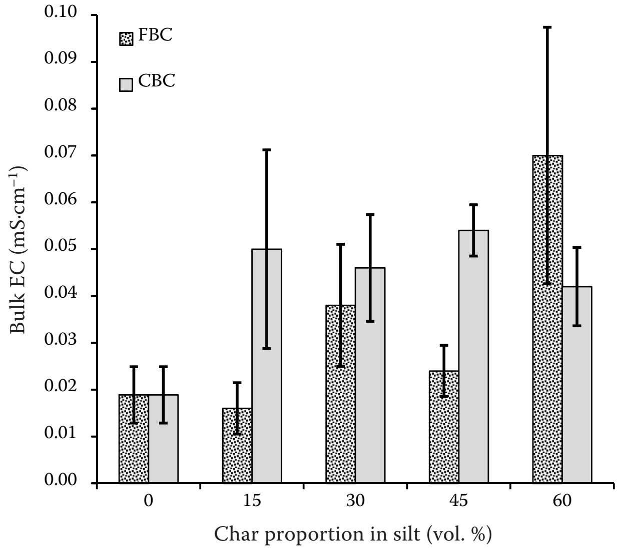

Fig. 3. Average electrical conductivity in the different growing media during the experiment (mean ± SD)

was relatively low (< 0.11) in all the media as a consequence of non-fertilization (Fig. 3).

Seedling heights were measured weekly. Pot positions were changed twice a week to reduce variation in growing conditions. After 9 weeks, seedlings were harvested and measured for morphological attributes, including root volume as described above.

In the seedling growing experiment, the effect of the growing medium on the attributes of seedlings and growing media was tested using two-way (factors = BC type, n = 2 and volume proportion, n = 5) and one-way (factor = mix, n = 10) analysis of variance (SPSS software, SPSS Inc, Chicago, USA). The significance of differences between means was tested using Tukey's test with one-way ANOVA and the LSD test with two-way ANOVA.

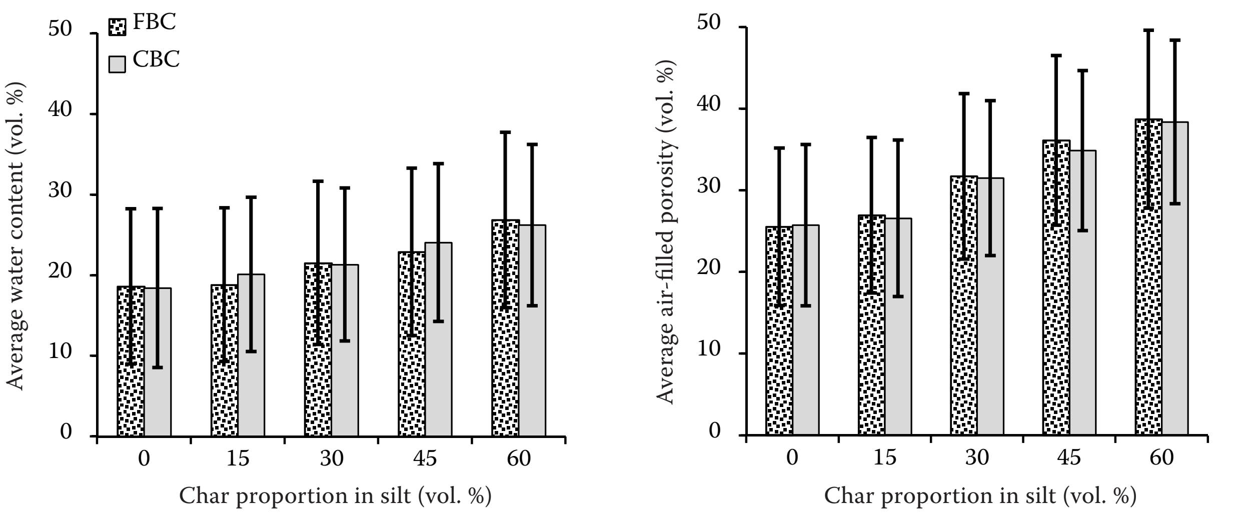

Fig. 2. Average water content and air-filled porosity in the different growing media during the experiment (mean ± SD)

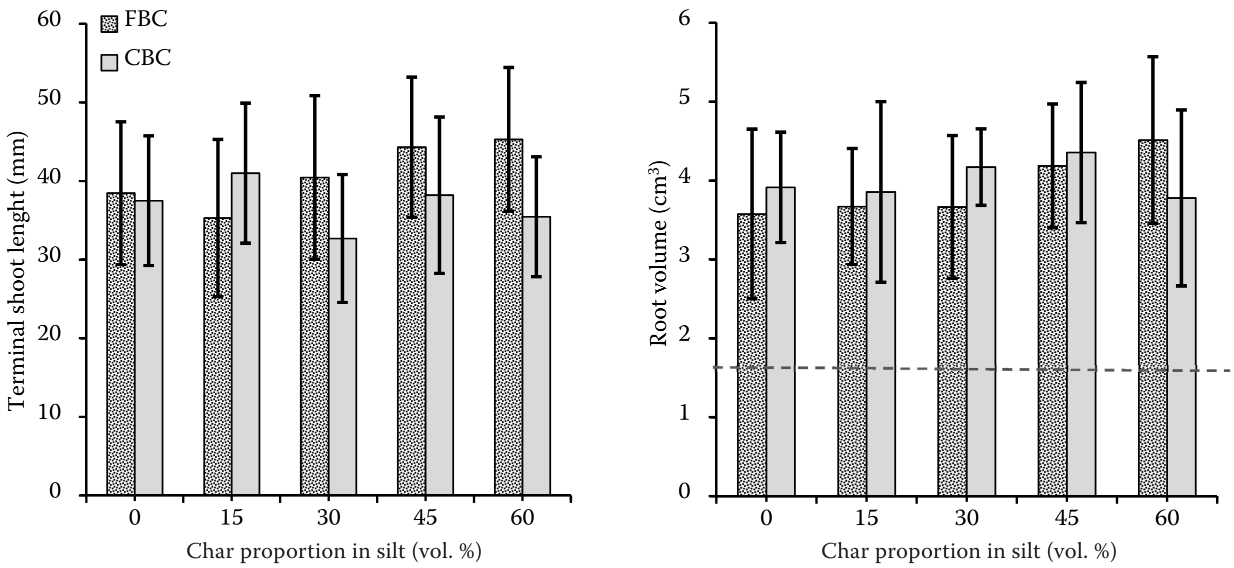

Fig. 4. Average length of the terminal shoots and root volumes in the different growing media after the experiment (mean ± SD), vertical line denotes the initial mean root volume

RESULTS

The length of the new terminal shoot differed among the growing media (P = 0.020 one-way ANOVA); FBC60 had significantly longer shoot than CBC30 (P = 0.020 Tukey) (Fig. 4). Two-way ANOVA showed a significant main effect between the two BC types (P = 0.028) and interaction effect of BC type and mix proportion (P = 0.028). Differences prevailed between FBC and CBC in proportions of 30% (P = 0.031 LSD) and 60% (P = 0.007 LSD).

Mean seedling height varied little (22.3–23.7 cm) in the different growing media after the experiment and no significant main effect was observed [P > 0.05 one-way-ANOVA, initial height (19.6 cm) as a covariate]. Two-way ANOVA showed no significant difference in the BC type, mix proportion, or the interaction of BC type and mix proportion (P > 0.05). However, some differences prevailed among FBC media (P = 0.028 LSD) and between FBC60 and CBC60 (P = 0.021 LSD).

Root volume (initially 1.54 cm^3) showed no difference among the growing media after the experiment (P > 0.05 one-way and two-way ANOVAs) (Fig. 4). Two-way ANOVA revealed, however, a significant difference between FBC60 and CBC60 (P = 0.044 LSD). Mean root to shoot ratio decreased during growing from 0.37 to 0.24-0.35 by DM in the different growing media. Root to shoot ratio in CBC30 (mean ratio 0.35) differed significantly (P < 0.003 Tukey) from that in CBC0 (0.24), FBC30 (0.25) and FBC60 (0.25).

DISCUSSION

Our study indicated no negative effect of BC addition into soil on transplanted Norway spruce seedlings, even at the highest application rate (60 vol.%). In general, seedling growth attributes (seedling height, terminal shoot growth, root volume) differed only between BC types and only at the highest proportion used.

The relatively similar growth response among all growing media is probably because all the media had relatively low nitrogen content with respect to seedling requirements (Wall, Heiskanen 2003; Heiskanen 2013). In boreal forest soils, nitrogen is the most growth limiting nutrient; nitrogen in the humus layer is especially correlated with site quality (Tamminen 1993). In Finnish Norway spruce forests, nitrogen range on an organic matter basis is typically 15–30 $g \cdot kg^{-1}$ in the humus and mineral soil layers (Tamminen 1993). Soil nutrient availability can be enhanced, however, through increased cation retention and decreased phosphate adsorption after BC application (Nelson et al. 2011). BC added to agricultural soils may decrease soil nitrogen just after addition (Nelson et al. 2011; Tammeorg et al. 2012), suggesting a need for nitrogen fertilization in crop production. This may not be the case, however, in acidic forest soils where evidence suggests that BC can increase nitrification (Deluca et al. 2006; Ball et al. 2010; Nelson et al. 2011).

In conclusion, results of our bioassay suggest that BC can be applied at least up to 60 vol.% into silty soils without detrimental effects on outplanted seedlings and subsequent tree plantation success. Additional information from actual forest outplantings is still needed, however, on the effects of different BC types on soils with different physical and chemical properties and on plantation success over a longer period of time.

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