Changes in Root Growth and Physical Properties in Substrates Containing Charred or Uncharred Wood Aggregates©[1]

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INTRODUCTION

In recent years, biochar (BC) has attracted attention for use as a horticultural substrate amendment due to its potential benefits, such as promoting substrate/rootzone biology and nutrient holding/exchanging capacity. Biochar also has the potential to be a local and renewable substrate component produced from waste products and regionally available material (Peterson, 2013). The potential for horticultural use of BC in soilless substrates with greenhouse crops is clouded, however, because initial reports of BC in substrates do not show consistent results or benefits. There is a need to explore the impact of the vast range of BC properties on their potential use in greenhouse and nursery container production (Altland and Locke, 2012).

Biochar has been shown to be a potential use as a replacement for perlite in greenhouse mixes (Northup, 2013), because it is lightweight, porous, and it is thought to have potential economic benefit (cost savings) over perlite. Increased root growth has also been reported when BC was amended to a peat-based substrate (O'Hara, 2013); however quantification of increased root growth in biochar amended substrates has not been published.

To investigate the potential of using BC in greenhouse substrates, BC was produced with known/measurable parameters so that a definable and repeatable product was used in these studies. Mini-horhizotrons and rhizometers were used to quantify and observe root growth and changes in substrate physical properties amended with BC (Judd, 2013). The objectives of this study were: 1) to test the effects of BC and root growth on substrate physical properties over time, and 2) test the effects of BC amended substrate on plant root growth.

MATERIALS AND METHODS

Loblolly pine trees (*Pinus taeda* L.) were harvested and hammer-milled to yield 6.35 mm pine-wood chips (PWC). A portion of this material was reserved to test physical properties, and the rest of the material was used to produce biochar at North Carolina State University. The BC production system used in this study was a top-lit updraft gasifier (Boyette et al., 2012). On 17 Apr. 2014, 1.5 m^3 of the PWC material was loaded into the gasifier reactor using a conveyor to insure level placement of the material. The PWC material was lit at the top inside the gasifier reactor, and then the reactor was quickly closed to control the gasification of the material. Combustion was sustained by regulating the amount of air entering from the bottom (500 $f{\cdot}min^{-1}$) and passing up through the material. A vent at the top of the reactor allowed combustible gas from the process to leave the system, and this gas was lit to reduce the amount of smoke produced. A temperature probe inside the reactor measured the internal temperature of the flame front and resulting BC as the front passes. The temperature of the flame front during this production was 720°C. Once the flame front reached the bottom of the gasifier, the air flow was shut off and compressed nitrogen gas was then fed through from the bottom for 24 h, prevent any flare up as the BC cooled. Once cooled, the BC was removed from the reactor and stored in 1.5 m^3 industrial bags under shelter.

[1] Second Place – Graduate Student Research Paper Competition.

Rhizometers

Three substrates were used: 4 peat moss and 1 perlite (PL) (v/v), PWC, or BC. All substrates were tested for initial pH and then amended with dolomitic limestone at 3.56 $kg·m^{-3}$ to achieve a target pH of 5.8. Forty rhizometers were filled with one of the three substrates, with the same amount of substrate (≤5%), and tapped five times to achieve a similar bulk density in each rhizometer. Marigold (*Tagetes erecta* 'Inca Orange') plugs were planted into 20 of the packed rhizometers and the other 20 rhizometers were left fallow. Rhizometers were completely randomized in the greenhouse. Initial substrate physical properties indicated similar container capacity among the substrates; therefore all rhizometers were irrigated similarly by hand, as needed depending on weather conditions. Plants were fertilized at each watering with 200 ppm nitrogen with Peters Professional® 20-10-20 Peat-Lite Special (The Scotts Co., Marysville, Ohio).

Once a week [7, 14, 21 and 28 days after planting (DAP)], ten rhizometers were harvested, of which five had marigold plants and five were fallow. These rhizometers were then used in the NCSU Porometer method (Fonteno et al., 1995) to determine substrate physical properties, including total porosity (TP), container capacity (CC) and air space (AS). Data were subjected to the general linear model procedures (SAS Institute version 9.3, Cary, North Carolina). Means were separated by Least Significant Differences (LSD) at $P≤0.05$.

Mini-Horhizotrons

Three substrates were used: 4 peat moss and 1 perlite (PL) (v/v), pine-wood-chips (PWC), or biochar (BC). All substrates were tested for initial pH and then amended with dolomitic limestone at 3.85 $kg·m^{-3}$ to achieve a target pH of 5.8. Four mini-Horhizotrons were divided in the center to separate each of the three chambers and allowed for one of the three substrates to fill the chamber. Previous work has been done to indicate the capability of the mini-horhizotron to have a different substrate in each chamber without significantly affecting root growth (Judd et al., 2014). Once filled, the divider was gently removed, allowing for each substrate to be united in the center, where one plug of tomato (*Solanum lycopersicum* 'Roma') was planted. Mini-horhizotrons were randomly placed on a greenhouse bench and irrigated similarly by hand as needed (since the CC of all three substrates was similar). Plants were fertilized at each watering as described above.

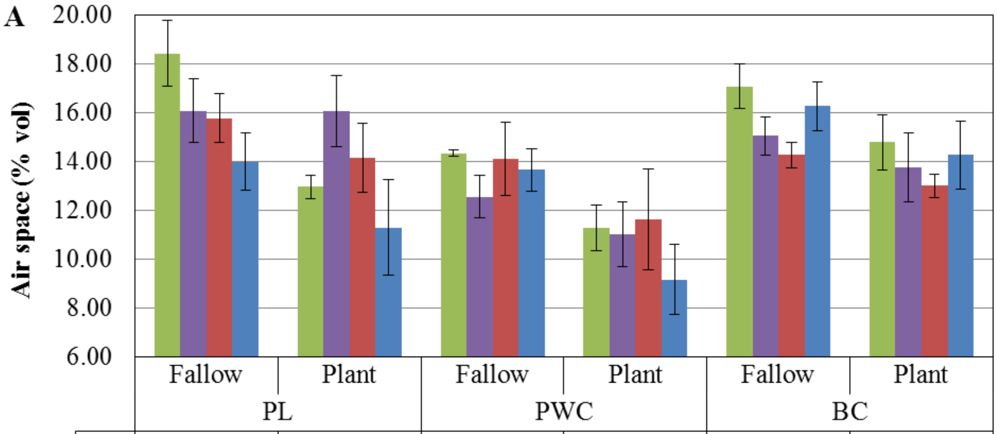
Root length measurements (cm) were taken on the three longest roots appearing on the clear side of each chamber every 3 DAP until 21 DAP. Each chamber has two measureable chamber sides (and six measured roots) for each substrate in one mini-horhizotron. At 21 DAP, the study was terminated and shoots were removed at the substrate surface in the mini-horhizotrons. The root balls in the mini-horhizotrons were removed and the different substrate sections were separated and roots removed/washed, in order to determine root mass within the specific substrate in which it was growing. Data were subjected to the general linear model procedures, and root length measurements were subjected to regression analysis. Means were separated by LSD at $P≤0.05$.

RESULTS

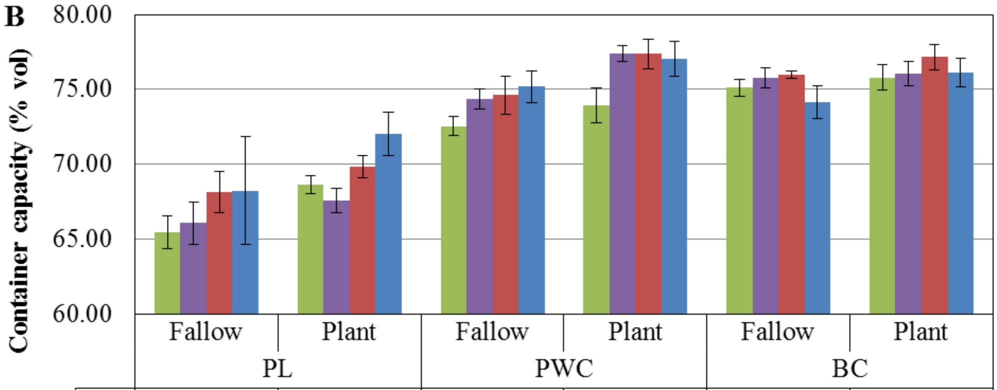
Rhizometers

For the PL substrate, there were no differences between planted and fallow rhizometers for TP, CC, and AS at all of the measurement dates except at 7 DAP when planted rhizometers had increased CC and decreased AS compared to fallow rhizometers (Fig. 1; TP data not shown). For the PWC substrate, at 7 and 28 DAP the planted rhizometers had decreased AS compared to fallow, and at 14 DAP planted rhizometers had increased CC compared to fallow. For the BC substrate, there were no differences between planted and fallow rhizometers for TP, CC, and AS at all of the measurement dates. Comparing the planted rhizometers among the three substrates, the BC substrate was similar to the PWC substrate and greater than the PL substrate in CC at all measurement dates; and BC substrate was similar to PL substrate in AS at all measurement dates (Figs. 1A and B).

Comparing the fallow rhizometers, BC substrate was similar to both the PL and PWC substrates in AS; and for CC, the BC substrate was similar to PWC substrate.



DAP	PL Fallow	PL Plant	PWC Fallow	PWC Plant	BC Fallow	BC Plant
7	18.42 a	12.95 ab	14.33 b	11.28 b	17.06 ab	14.78 a
14	16.06 a	16.06 a	12.55 b	11.01 b	15.04 ab	13.76 ab
21	15.77 a	14.16 a	14.10 a	11.63 a	14.26 a	13.00 a
28	13.98 a	11.28 ab	13.64 a	9.15 b	16.26 a	14.26 a



DAP	PL Fallow	PL Plant	PWC Fallow	PWC Plant	BC Fallow	BC Plant
7	65.44 c	68.62 b	72.55 b	73.93 a	75.12 a	75.80 a
14	66.07 b	67.56 b	74.33 a	77.40 a	75.80 a	76.04 a
21	68.14 b	69.86 b	74.61 a	77.38 a	76.00 a	77.16 a
28	68.24 a	72.05 b	75.18 a	77.03 a	74.16 a	76.12 a

Fig. 1. (A) Air space for three substrates, 80% peat amended with 20% perlite (PL), pine-wood-chips (PWC), or biochar (BC) for both fallow and planted Rhizometers. (B) Container capacity for three substrates, 80% peat amended with 20% PL, PWC or BC for both fallow and planted Rhizometers. Standard errors bars are shown to represent means separation ($P \leq 0.05$). Tables below graphs show the means separation among substrates for fallow or planted Rhizometers, separated by days after planting (DAP).

Mini-Horhizotrons

In the beginning of the study, tomato roots growing in both the BC and PL substrate had greater root growth than roots in the PWC substrate (Fig. 2A). From 15 DAP until the end of the study, roots growing the in PL substrates were similar to the roots growing in the PWC substrate, however roots growing the BC substrates were longer than roots in the PWC substrate. Data from the dry weight analysis indicates that root growth was not different among the substrates at the termination date (21 DAP; Fig. 2B).

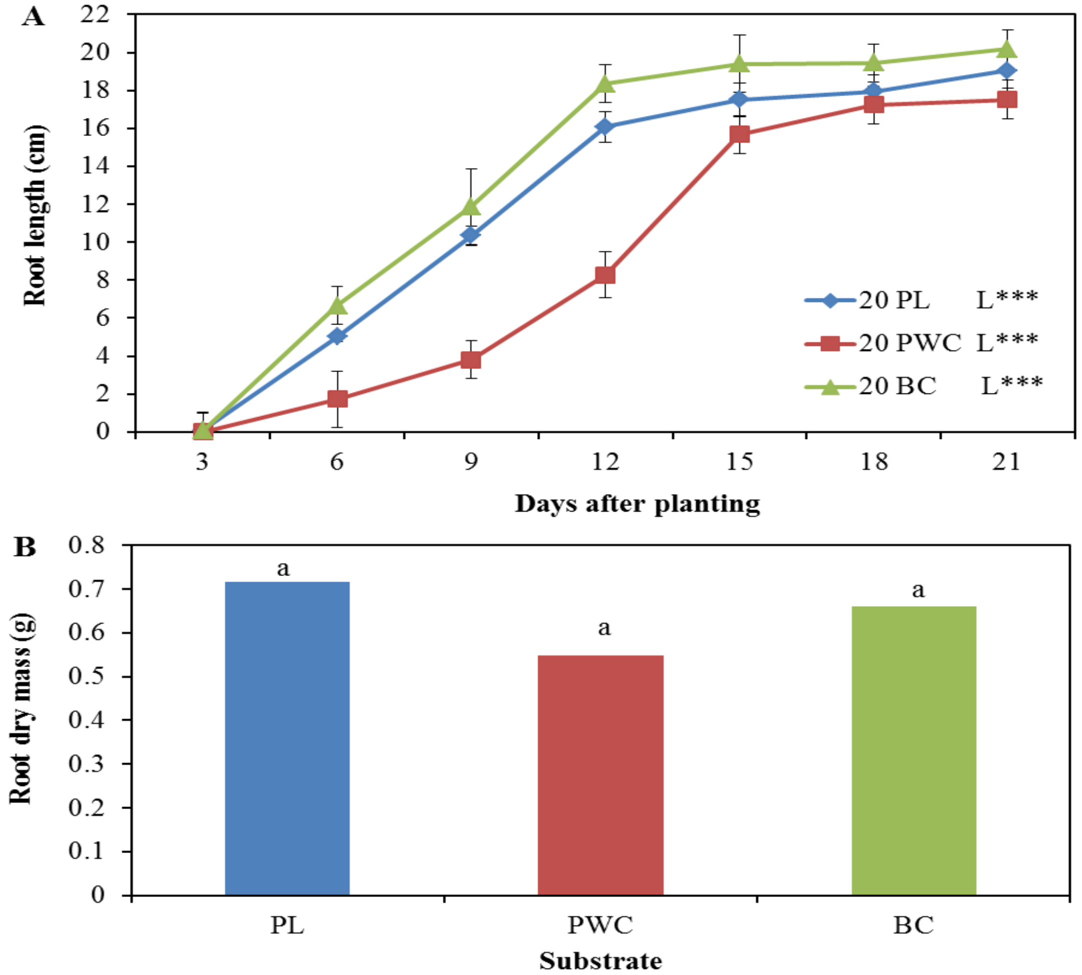


Fig. 2. (A) Root length measurements of tomato (*Solanum lycopersicum* 'Roma') plants in mini-Horhizotrons when grown in 80% (v/v) peat amended with 20% of perlite (PL), pine-wood-chips (PWC) or biochar (BC) with error bars representing means separation ($P \leq 0.05$). L*** represents significant linear effects when $P \leq 0.001$. (B) Root dry mass of tomato plants grown in mini-Horhizotrons, means separated across substrates by Least Significant Difference (LSD; $P \leq 0.05$), and same letter indicates means are not significantly different.

DISCUSSION

Data from the substrate physical properties provide evidence that peat amended with BC at 20% (v/v) creates a comparable substrate environment as when amended with PL or PWC. Substrate settling due to irrigation seemed to have a greater effect on substrate physical properties than the marigold roots, due to the physical properties in both the fallow and planted rhizometers increasing/decreasing at the same rate. There were observable differences in root growth along the clear chambers of the mini-Horhizotron, with greater root growth in BC substrate compared to roots in the PWC substrate. This could be due to the charring process, as there may be a potential organic compound in charred material that promotes root growth (Kochanek et al., 2014).

This work provides additional evidence of the potential use of biochar in greenhouse substrates for crop production. This study indicates that BC can blend with peat similar to perlite and produce substrates with similar physical properties. Tomato roots growing in the 20% BC substrate were similar in length to roots growing in the PL substrate, indicating that BC may be suitable as a PL replacement. Biochar has other potential advantages over PL, such as opportunity to sequester carbon (Dumroese et al., 2011), possible lime reduction/replacement for pH modification (Northup, 2013), and using unstable or waste materials as a feedstock to produce a beneficial amendment.

Literature Cited

Altland, J.E. and Locke, J.C. 2012. Biochar affects macronutrient leaching from a soilless substrate. HortScience 47:1136-1140.

Boyette, M.D., Macialek, J.A. and Alston, B.P. 2012. The rapid production of biochar. ASABE Annu. Intl. Mtg., Texas, 29 July – 1 Aug. 2012.

Dumroese, R.K., Heiskanen, J., Englund, K. and Tervahauta, A. 2011. Pelleted biochar: chemical and physical properties show potential use as a substrate in container nurseries. Biomass Bioenerg. 35:2018-2027.

Fonteno, W.C., Hardin, C.T. and Brewster, J.P. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory, North Carolina State University.

Graber, E.R., Harel, Y.M., Kolton, M., Cytryn, E., Silber, A., David, D.R., Tsechansky, L., Borenshtein, M. and Elad, Y. 2010. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337:481-496.

Judd, L.A. 2013. Rhizometrics: novel techniques to observe and measure root growth of container-grown crops. North Carolina State University, North Carolina. M.S. Thesis.

Judd, L.A., Jackson, B.E., Fonteno, W.C. and Yap, T.C. 2014. Mini-Horhizotron: An apparatus for observing and measuring root growth of container-grown plant material in situ. HortSci. (in press).

Kochanek, J., Swift, R. and Flematti, G. 2014. A systems approach to recycling organics for horticulture: Comparing emerging and conventional technologies. Paper Presented at 29th International Horticultural Congress: Symposium 30 - Organic Waste to Horticultural Resource, 18 August 2014, Brisbane, Queensland, Australia

Northup, J.I. 2013. Biochar as a replacement for perlite in greenhouse soilless substrates. Iowa State Univ., Ames, M.S. Thesis 13399.

O'Hara, R. 2013. Students evaluate bio char in soil. Greenhouse Grower 31:43.

Peterson, E. 2013. Black gold. Digger 57:13-16.