Comparison of Charred and Uncharred Wood Aggregates in Horticultural Substrates

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Index Words: biochar, greenhouse media, root growth

Significance to Industry: This work provides additional evidence of the potential use of biochar in greenhouse substrates for crop production. However, biochar can be produced using different methods, temperatures, and feedstock, which will affect the chemical and physical properties of the final biochar product. Therefore, it is important to know and measure the conditions of producing biochar in order to understand how and why it affects substrates and crop production. Biochar can then also be produced consistently, and potentially producing more consistent results with crop production. This study indicates that biochar can be mixed with peat similar to perlite and produce substrates with similar physical properties. Chemical analysis reported a wide pH increase after the substrates were limed, indicating that there are properties of biochar that will aid in pH increase of peat substrates and could affect pH buffering. Plant root growth was not negatively affected by the presence of biochar in the substrate, further aiding in the potential use of biochar in substrates for container production.

Nature of Work: Interest in using biochar for horticultural purposes has increased substantially in recent years due to its potential benefits, such as high carbon content and nutrient holding/exchanging capacity. Biochar also has the potential to be a local and renewable product, produced from waste products and/or regionally available material (8). There are many parameters that affect the end-product when making biochar, including feedstock, particle size of feedstock, burn temperature, and time of pyrolysis/charring. These factors alter the physical and chemical properties of biochar as well as how the biochar performs in soil or soilless substrates. There is potential for horticultural use of biochar in soilless substrates used for container production of greenhouse crops (6); however reports of the influence of biochar on substrates do not show consistent benefits. This could be due to the wide range of feedstock used to produce biochar, from organic wastes to peanut hulls, which could alter nutrient composition in the final biochar product. There is a need to explore the impact of the vast range of biochar properties on their potential use in greenhouse and nursery container production (1).

Biochar has potential as a substrate replacement for perlite, as both are lightweight and porous, as well as a potential economic benefit (cost savings) since perlite is the most

expensive (by volume) individual component in greenhouse/perennial substrates. Research has shown improved plant growth when biochar (produced from citrus wood in a charcoal pit) was amended with coir and tuff (4). Improved plant growth was also reported when biochar (produced from hardwood at commercial charcoal-production company) was added to sphagnum peat (6). Increased root growth was reported when biochar was amended with a peat-based substrate (7), however quantification of increased root growth in biochar amended substrates has not been published. Most reports using biochar do not provide sufficient data on the processing and repeatability of biochar production.

To investigate the potential of using biochar in greenhouse substrates, biochar needed to be produced with known/measurable parameters so that the end product is consistent. To investigate the effect of biochar on root growth, mini-Horhizotrons were used to quantify and observe root growth and development (5). The objectives of this study were 1) to test the effects of biochar on substrate physical and chemical properties, and 2) test the effects of biochar amended substrate on plant root growth using mini-Horhizotrons.

Loblolly pine trees (*Pinus taeda* L.) were harvested and hammer-milled to yield 6.35 mm (0.25 in.) pine-wood-chips (PWC). A portion of this material was reserved to test chemical and physical properties, and the rest of the material was used to produce biochar at North Carolina State University. The biochar production system used in this study was a top-lit updraft gasifier (2). On 17 April 2014, 1.5 m^3 (2 yd^3) of the PWC material was loaded into a large 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 (96.2 $ft^3 \cdot min^{-1}$ or 2.7 $m^3 \cdot min^{-1}$) 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 biochar as the front passes. The temperature of the flame front during this production was 720° C (1328° F). The external temperature of the reactor was measured with an infrared thermometer (Westward #2ZB46, UK) to determine speed of the flame front and to ensure the flame front was, in essence, level. 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 biochar cooled. Once cooled, the char was removed from the reactor and stored in 1.5m^3 (2 yd^3) industrial bags under shelter.

The study was executed on 14 May 2014 in greenhouses at North Carolina State University, Raleigh, NC. Six substrates were used: peat moss at 90% (v/v) amended with 10% perlite (PL), pine-wood-chips (PWC), or biochar (BC), and peat moss at 80% (v/v) amended with 20% PL, PWC or BC. Substrates were mixed on 12 May 2014, and all substrates were tested for initial pH and then amended with dolomitic limestone at

3.85 kg·m^{-3} (6.5 lb·yd^{-3}) to achieve an expected pH of 5.8. The substrates containing biochar had a beginning pH of 3.7, and sufficient lime was added to those substrates to raise the pH to an optimal level (5.8). On 14 May 2014, eight mini-Horhizotrons were divided in the center to separate each chamber and allowed for a different substrate to fill the chamber. Four mini-Horhizotrons were divided and each chamber was randomly chosen to be filled with one of the 90:10 peat:aggregate (PL, PWC or BC) substrates. The other four mini-Horhizotrons were divided and each chamber filled with one of the 80:20 peat:aggregate substrates. The mini-Horhizotron chambers were filled with an individual substrate and the whole mini-Horhizotron was tapped three times, by lifting the mini-Horhizotron 10 cm (4 in.) from a hard surface and gently dropping, to settle the substrate. Mini-Horhizotrons were then filled to the top with substrate again, to accommodate for substrate settling which occurs after initial irrigation events in the greenhouse. 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. Twenty-four 10 cm (4 in. dia.) greenhouse containers were also filled, four per each substrate, to be used for substrate chemical analysis (pH and EC measurements). Tomato plugs were planted in the center of the containers as well. Mini-Horhizotrons and containers were placed in the greenhouse and plants in each substrate were overhead watered as needed depending on weather conditions, and never showed symptoms of water stress. Plants were fertilized at each watering with 200 ppm nitrogen with Peters Professional 20-10-20 Peat-Lite Special (The Scotts Co., Marysville, OH).

Root length measurements (cm) were taken on the three longest roots appearing on the clear side of each chamber every 3 days after planting (DAP) until 21 DAP. Each chamber has two measureable sides giving a sum of two chamber sides for each substrate in one mini-Horhizotron. Measurements were taken by placing a transparent sheet (3M Visual Systems Division, Austin, TX) with a 0.39 x 0.39 in. grid on each face, and roots were measured from the center of the mini-Horhizotron to the end of the gridlines, which reached the end of the chamber. Once a week, a pour-through was conducted on the container-grown plants to measure the pH and electrical conductivity (EC) of every substrate according to the pour-through extraction procedure (9) using a Hanna pH/EC meter (HI 9811, Hanna Instruments, Ann Arbor, MI). On 4 June 2014, 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 varying substrate sections were carefully cut 5 cm (2 in.) from the center, in order to determine root mass within the specific substrate in which it was growing. Roots were then carefully washed to remove substrate in preparation for dry weight determination. Both the shoots and washed root systems were dried at 70° C for 48 h. Data were subjected to the general linear model procedures, and root length measurements, pH and EC was subjected to regression analysis (SAS Institute version 9.3, Cary, NC). Means were separated by least significant differences at $P \leq 0.05$.

Physical properties including air space (AS), container capacity (CC) and total porosity (TP) were determined for each substrate blend at experiment initiation using the North

Carolina State University Porometer method (3). Properties were determined using three representative samples of each substrate. To determine particle size distribution of the three aggregates (PL, PWC and BC), four samples of each aggregate were dried at 105° C for 48 h and placed in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, OH) fitted with seven sieves; 6.3 mm (0.25 in.), 2mm (0.08 in.), 0.71 mm (0.03 in.), 0.5 mm (0.02 in.), 0.25 mm (0.009 in.), and 0.106 mm (0.004 in.) for five min. The sample from each sieve was weighed, and particle size was expressed as a percentage of the total weight of the sample. Data from physical property analyses were subjected to the general linear model procedures and means were separated by least significant differences at $P \leq 0.05$.

Results and Discussion: Chemical analysis of the substrates revealed that at 5 DAP, the pH for all substrates were above 6.5 (Table 1). The initial pH of the PWC and BC aggregates were 4.2 and 7.0, respectively. When making the substrates, initial pH of the biochar substrates was similar to other research reports (6). Substrate pH was measured after lime was added and these pH values were approximately 5.8 for all substrates. Biochar aggregates may contain bicarbonates that will raise substrate pH (6), however there was a large increase in pH of all the substrates and therefore this increase could be due to other factors, such as the reaction between the peat and lime addition. At 5 DAP, the pH of 10% BC and PWC substrates were higher than the 10% PL (Table 1). At 12 DAP, the 10% PWC substrate was higher than the other substrates, and at 19 DAP there were no differences among the substrates. The pH for the 20% substrates was only different at 12 DAP, when 20% PWC substrate was greater than the other substrates. Electrical conductivity for both the 10% and 20% substrates increased from 5 to 12 DAP, and dropped lower at 19 DAP (Table 1). Comparing the PL and BC substrates, EC was not different at all measuring dates, indicating that the biochar aggregate used appears to have no significant nitrogen drawdown/tie-up.

Substrate physical properties indicate that there are no differences among the 10% PL, PWC or BC substrates for all properties (Table 2). For 20% BC substrate, there was greater TP and CC, with lower AS. This could be due to the greater amount of fines and medium-sized particles found in the biochar aggregate that fill in pores in the peat and lower AS and raise CC (Table 2). This indicates that charring process caused a significant difference in particle size distribution; the process reduced the size of the larger PWC particles and created more medium and fine BC particles. 20% PWC substrate had greater AS with lower CC, and this could be due to the PWC aggregate having lower amounts of medium-sized and fine particles. 20% PL had a lower TP compared to 20% BC, however for CC and AS for the two substrates were not different. Both PL and BC aggregates had similar extra-large, large and fine particles, but BC had greater amounts of medium-sized particles than PL. Replacing PL with BC in peat substrates created comparable physical environments for the tomato plants.

In the substrates with 90% peat amended with 10% PL, PWC or BC, tomato root lengths measured from 3 to 6 DAP were not different (Fig. 1A). At 9 DAP, roots in the 10% PL substrate were significantly longer than roots in the other substrates. At 12

DAP, roots growing in 10% PL and PWC were significantly longer than roots growing in the 10% BC substrate. After 15 DAP, there was no difference in tomato root growth among the three substrates. Although differences were observed in root growth among the substrates from 9 to 12 DAP, roots growing in 10% BC caught up in length to the other substrates by the next measurement date. Data from the dry weight analysis indicates that root growth was not different among the substrates (Fig. 2A). By the end of the study (21 DAP), there was no differences in root growth among the substrates, with root growth and mass comparable between 10% PL and BC.

In the substrates containing 80% peat with 20% PL, PWC or BC, tomato root lengths show differences from 6 DAP until 21 DAP. At 6 and 12 DAP, roots growing in 20% BC were significantly greater than roots growing in the other substrates (Fig. 1B). At 9 and 21 DAP, tomato roots growing in 20% PL and BC were longer than roots growing in 20% PWC. Data from the dry weight analysis indicates that root growth was not different among the substrates (Fig. 2B). There were observable differences in visible root growth along the sides of the mini-Horhizotron, with greater root growth in 20% BC substrate compared to roots in the 20% PWC substrate. This could be due to the charring process; the 20% BC substrate seemed to stimulate root growth. However, by the end of the study root mass in the substrate (not all visible) was similar among the substrates.

Literature Cited:

1. Altland, J.E. and J.C. Locke. 2012. Biochar affects macronutrient leaching from a soilless substrate. HortScience 47:1136-1140.
2. Boyette, M.D., J.A. Macialek, and B.P. Alston. 2012. The rapid production of biochar. ASABE Annu. Intl. Mtg., Texas, 29 July – 1 Aug. 2012.
3. Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory, North Carolina State University.
4. Graber, E.R., Y.M. Harel, M. Kolton, E. Cytryn, A. Silber, D.R. David, L. Tsechansky, M. Borenshtein, and Y. Elad. 2010. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337:481-496.
5. 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.
6. Northup, J.I. 2013. Biochar as a replacement for perlite in greenhouse soilless substrates. Iowa State Univ., Ames, M.S. Thesis 13399.
7. O'Hara, R. 2013. Students evaluate bio char in soil. Greenhouse Grower 31:43.
8. Peterson, E. 2013. Black gold. Digger 57:13-16.
9. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

Table 1. pH and electrical conductivity (EC) of all substrates used in mini-Horhizotron study.

		Days after planting (DAP)					
		5		12		19	
Ratio[z]	Substrate	pH	EC	pH	EC	pH	EC
90:10:00	PL[y]	6.6 b[x]	1.04 a	6.6 b	1.07 a	6.6 a	0.66 a
	PWC[w]	6.7 a	0.80 b	6.7 a	1.04 a	6.6 a	0.66 a
	BC[v]	6.7 a	1.04 a	6.6 b	1.11 a	6.6 a	0.66 a
80:20:00	PL	6.8 a	1.05 a	6.6 b	1.03 ab	6.8 a	0.74 a
	PWC	6.8 a	0.80 a	7.0 a	0.92 b	6.9 a	0.68 a
	BC	6.8 a	0.88 ab	6.8 b	1.06 a	6.9 a	0.74 a

[z]Ratio = peat substrate amended with PL, PWC or BC as specified percent ratios (v/v).

[y]PL = peat amended with perlite.

[x]Means separated within columns by DAP and ratio for chemical properties distribution by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.

[w]PWC = peat amended with pine-wood-chips, PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly (*Pinus taeda* L.) pine logs.

[v]BC = biochar aggregate used in making substrates for this study; BC is produced by PWC gasification.

Table 2. Physical properties of all substrates used in a mini-Horhizotron experiment and particle size distribution of the aggregates amended in the substrates.

		Physical properties[z]		
Ratio[y]	Substrate	Container capacity[x] (% vol)	Air space[w] (% vol)	Total porosity[v] (% vol)
90:10	PL[u]	69.7 a[t]	21.1 a	90.8 a
	PWC[s]	70.2 a	21.1 a	91.3 a
	BC[r]	72.0 a	20.2 a	92.0 a
80:20	PL	68.2 ab	21.9 ab	90.1 b
	PWC	62.9 b	28.0 a	91.0 ab
	BC	71.2 a	20.5 b	91.7 a

	Particle size distribution[q] (% weight)			
	X-Large (>6.3 mm)	Large (6.3>2.0 mm)	Medium (2.0>0.5 mm)	Fine (≤0.5 mm)
PL[p]	0.12 b[o]	60.36 b	28.78 b	10.74 a
PWC[n]	1.56 a	78.95 a	19.03 c	0.46 b
BC[m]	0.37 b	48.88 b	46.44 a	4.39 ab

[z]Physical properties data were collected from three samples per substrate and represented as means. Analysis performed using the North Carolina State University Porometer method (Fonteno et al., 1995).
[y]Ratio = peat substrate amended with PL, PWC or BC as specified percent ratios (v/v).

[x]Container capacity = (wet weight – oven dry weight) ÷ volume of the sample.

[w]Air space = volume of water drained from the sample ÷ volume of the sample.

[v]Total porosity = container capacity + air space.

[u]PL = peat amended with perlite.

[t]Means separated within columns by ratio for physical properties by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.
[s]PWC = peat amended with pine-wood-chips, PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly (*Pinus taeda* L.) pine logs.
[r]BC = peat amended with biochar, BC is produced by PWC gasification.

[q]Particle size distribution data were collected from four samples per aggregate and represented as mean percent by weight of the samples. Analysis performed using Ro-tap Shaker (Model B, W.S. Tyler, Mentor, Ohio) fitted with seven sieves; 6.3 mm (0.25 in.), 2mm (0.08 in.), 0.71 mm (0.03 in.), 0.5 mm (0.02 in.), 0.25 mm (0.009 in.), and 0.106 mm (0.004 in.).
[p]PL = perlite aggregate used in making substrates for this study.

[o]Means separated within columns for particle size distribution by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.

[n]PWC = pine-wood-chip aggregate used in making substrates for this study; PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly pine logs.

[m]BC = biochar aggregate used in making substrates for this study; BC is produced by PWC gasification.

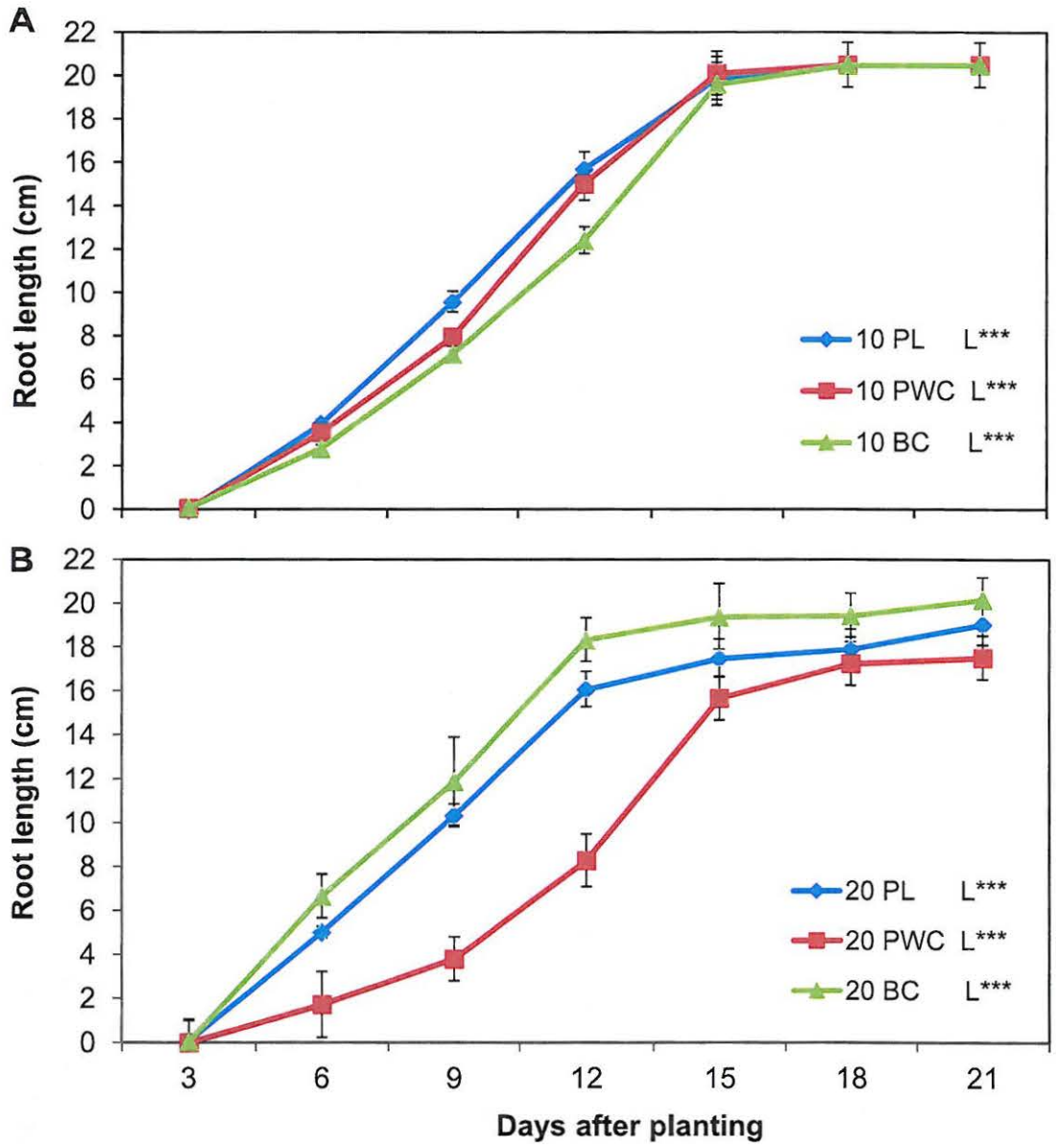

Figure 1. Root length measurements (1 cm = 0.394 in.) of tomato (*Solanum lycopersicum* 'Roma') plants in mini-Horhizotrons when grown in (A) 90% (v/v) peat amended with 10% of perlite (PL), pine-wood-chips (PWC) or biochar (BC) with error bars representing means separation ($P \leq 0.05$). (B) Root length measurements of plants in the mini-Horhizotrons when grown in 80% (v/v) peat amended with 20% PL, PWC or BC, with error bars representing means separation ($P \leq 0.05$). Letters next to substrate represent linear regression significance; L*** represents significant linear effects when $P \leq 0.001$.

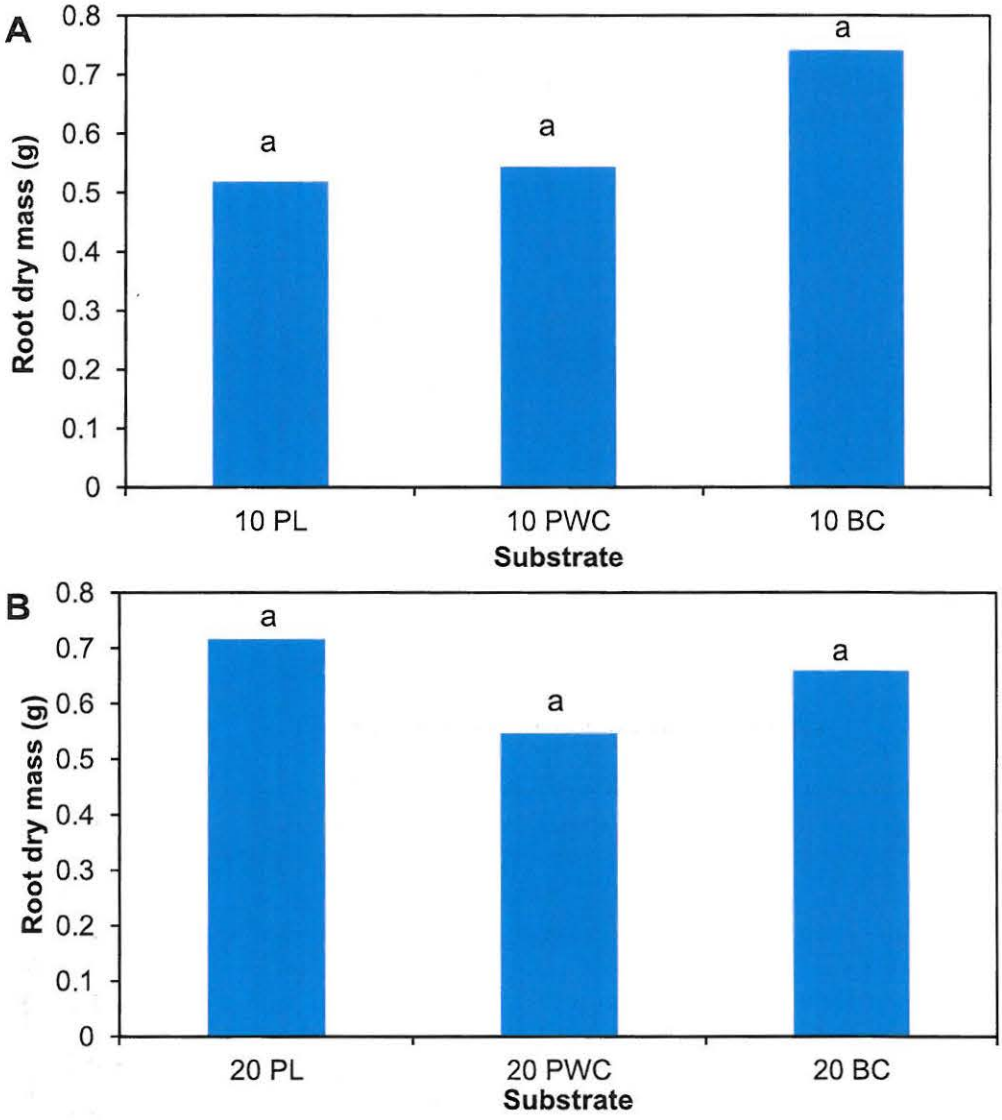

Figure 2. Root dry mass of tomato (*Solanum lycopersicum* 'Roma') plants grown in mini-Horhizotrons. (A) Root dry mass of plants grown in 90% (v/v) peat amended with 10% perlite (PL), pine-wood-chips (PWC) or biochar (BC). (B) Root dry mass of plants grown in 80% (v/v) peat amended with 20% PL, PWC or BC. Means separated across substrates by ratio by Least Significant Difference (LSD; $P \leq 0.05$), and same letter indicates means are not significantly different.