Effect of Biochar on Nutrient Release and Retention in Container Crops

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Significance to Industry Greenhouse and nursery producers are facing increasing fertilizer costs and low nutrient use efficiency. Water management strategies should be based on economic and environmental concerns and modified to increase nutrient uptake efficiency and reduce nutrient losses. Incorporating biochar into nursery substrate can potentially increase substrate fertility by increasing its capacity to retain water and nutrients. This research focused on the use of switchgrass (*Panicum virgatum*) biochar on nitrate (NO_3^-), phosphate (PO_4^-) and potassium (K^+) release and retention during 8-week life cycle of *Buxus sempervirens* ×*B. microphylla* ('Green Velvet' boxwood) and *Hydrangea paniculata* (Pinky Winky® hardy hydrangea). Pots were filled with pine bark and amended with either 10% or 25% (v/v) biochar. Plants were irrigated with a moisture sensor-based irrigation when the volumetric water content reach the set point of 0.25 cm^3/cm^3 and provided water until container capacity to determine the impact of biochar on water and nutrient leaching. Over the growing season the mass of NO_3^- and PO_4^{3-} released was not significantly different in each treatment in hydrangea, whereas K^+ release fluctuated more in the biochar amended substrates. In boxwood 25% biochar treatment released higher NO_3^- and PO_4^{3-} in leachate over the time while the mass of potassium had greater fluctuations during the growing season. Although the average of leachate analysis over the time showed a higher amount of PO_4^{3-} and K^+ was leached from containers that received 25% biochar, the total amount of water leached and nutrients lost from hydrangea containers were lower in biochar amendment pots in comparison to unamended pots due to improvements in the water holding capacity of the substrate and fewer irrigation events in the biochar treatments. The total amount of nutrient lost from boxwood was higher in biochar treatments but there were no differences in the number of irrigation events in boxwood.

Nature of Work Greenhouse and nursery producers are facing increasing fertilizer costs and low nutrient use efficiency (1). In containerized crop production excessive nutrients are typically supplied in order to prevent plant growth restriction (2). This, in combination with the low water and nutrient holding capacity of traditional container substrates, results in leaching and runoff. Future management strategies should be based on economic and environmental concerns and modified to increase nutrient uptake efficiency and reduce nutrient losses (3). Nutrient use efficiency is closely related to irrigation management (4). Minimizing nutrient losses through leaching may improve grower profits and sustainability by increasing fertilizer use efficiency, reducing fertilizer costs and avoid the need for the enforcement of non-point source of agrochemical pollution water quality regulations (5,6,7) and offer the potential to benefit the environment as well as growers (8). Biochar is a byproduct of pyrolysis, the thermochemical decomposition of organic materials in the absence of oxygen and at high temperatures, that can be used as soil conditioner in agriculture (9). Biochar has been described as a means to enhance soil nutrient retention (10). Moreover it can cause an increase in soil fertility in the long term via increase of cation exchange capacity and surface area and also increase water retention which can reduce nutrient leaching (11, 12). The objective of this study was to determine the effect of biochar on water conservation and nitrate (NO_3^-), phosphate (PO_4^-) and potassium (K^+) release and retention during 8-week life cycle of *Buxus sempervirens* ×*B. microphylla* (‘Green Velvet’ boxwood) and *Hydrangea paniculata* (Pinky Winky® hardy hydrangea).

The experiment was conducted at the University of Tennessee North Greenhouse Complex, Knoxville, Tennessee. ‘Green Velvet’ boxwood and hydrangea were potted into 3.8 L containers. Pots were filled with pine bark and amended with two rates of 10% or 25% by volume of biochar. Biochar was obtained from a local biochar producer and was made of 100% switchgrass subjected to pyrolysis at around 1000°C. Containers were watered by hand for 4 weeks before initiating the automatic sensor-based irrigation program. One week after transplanting, plants were top-dressed with 18N-6P_2O_5-12K_2O controlled release fertilizer with micronutrients (Osmocote, Everris, Marysville, OH) at 24 gram per container. Substrates were also treated twice with a surfactant (Aquagro, 600ppm) in order to prevent the substrate from becoming hydrophobic.

The experimental arranged in a randomized complete block design with 10 replications. Factors were two plant species (Buxus and Hydrangea) and 3 substrates [100% pine bark, pine bark with biochar (10% or 25% v/v)]. Analysis of variance was conducted using mixed models (SAS v9.4, Cary, NC), means were separated by plants using the slice option in order to compare the effect of biochar rate separately for each plant.

Substrate moisture levels were controlled by EC-5 capacitance sensors (ECHO-5, Decagon Devices Inc., Pullman, WA) connected to a multiplexer (AM16/32, Campbell Scientific Inc.) wired to a data logger (CR1000, Campbell Scientific Inc., Logan, UT) programmed to read and convert mV output from the EC-5 sensors to volumetric water content based on a substrate-specific calibration for each sensor. A 16-channel relay controller (SDM-CD16AC, Campbell Scientific Inc., Logan, UT) connected to the data logger operates solenoid valves. Ten independent irrigation zones were constructed with one irrigation line per treatment combination. When the data logger measured a lower volumetric water content (θ) than the set-point, it was programmed to supply power to the valve controlling irrigation to those containers. It turned on and off based on probe measurement of the volumetric water content of the substrate. For this experiment, the volumetric water content set point that triggered irrigation was 0.25 cm^3/cm^3, slightly greater than 0.20 cm^3/cm^3, which is an accepted value for plant available water in soilless substrates, in order to prevent the bark from becoming hydrophobic. The upper set point was based on the container capacity value of the most moisture retentive substrate, 0.41 cm^3/cm^3. All of the substrate treatments were irrigated with the same amount of water in order to compare the leachate volume to see the effect of biochar on water retention and nutrient leaching. Leachate volume was measured every day after each irrigation event. Leachate samples were collected from 50 containers, half of the containers, each week for eight weeks. The samples were stored in plastic vials, and were kept refrigerated until analyzed. At the time of analysis, leachate samples were filtered with a 0.45um syringe filter. The filtrate was then poured into 5-mL vials, capped, and analyzed on an ICS 1100 (Ion Chromatography System; Dionex, Bannockburn, IL) for concentrations of nitrate (NO_3^-), phosphate (PO_4^{3-}), and potassium (K^+).

Results and Discussion The irrigation event was scheduled based on probe measurements of substrate volumetric water content. The irrigation was applied once the set point (0.25 cm^3/cm^3) was reached until near container capacity (0.41 cm^3/cm^3). The real time monitoring of substrate volumetric water content of hydrangea showed that pine bark treatment set points was reached more frequently, whereas in the biochar treatments the plants were irrigated less frequently. Biochar treatments hold the water for longer period of time and require less frequent irrigation. After irrigation, plant water use and evapotranspiration resulted in a reduction in substrate water content, which was not different in boxwood plants treated with biochar from the control. Higher water requirement in addition to faster growth leads to faster drainage of hydrangea. Also, grown plants need more frequent irrigation. These factors influence the effect of biochar addition on substrate water holding capacity in hydrangea in comparison to boxwood which is a slow growth plant with low water requirements.

All nutrient concentrations were higher in 25% biochar treatment leachate; because the volume of leachate was different so the mass of nutrients (concentration * leachate volume) were calculated in order to look at the effect of biochar on nutrient release clearly. Nutrient analyses were averaged over two weeks to have the results for all of the treatments reported in 4 time periods, as some of the treatments were not irrigated every week. NO_3^- mass loss was not significantly different after increasing biochar amendment rate at individual time periods in hydrangea's leachate, whereas NO_3^- release fluctuated more in boxwood's leachate and increased in 25% biochar amendment rate in second and forth time periods (Table. 1). Higher biochar application rate produced higher PO_4^{3-} in leachate in both species. However the changes were not significant in hydrangea leachate. Over the growing season the mass of potassium released in leachate tended to fluctuated more in the biochar amended substrates. The mass of K^+ release increased after addition of 25% biochar at individual time periods in both of the plants. The higher mass of nutrient release in boxwood leachate might be due to lower nutrient requirements in a slow growing plant. Hydrangeas are fast growing plants with higher water and nutrient requirement in boxwood. These results are in line with the literature. Altland and Lock (2013) reported that gasified rice hull biochar act as a source of phosphate and potassium in soilless substrate (1).

The total amount of water leached and nutrients lost from hydrangea containers were lower in biochar amendment pots due to improvements in the water holding capacity of the substrate and fewer irrigation events in the biochar treatments.
Amendment with biochar was shown to affect concentration of PO43- and NO3- in both plants media and K+ in boxwood media. While concentration of the three aforementioned nutrients were higher in plants amended with 25% biochar compared to those not amended. Concentration of K+ in hydrangea was similar in all amended and unamended substrates (Table. 2). Dumroese (2011) reported that increasing pelleted biochar rates increased amounts of soluble iron (Fe), K, sodium (Na), P, and boron (B) and decreased levels of aluminum (Al), calcium (Ca), magnesium (Mg), manganese (Mn) and sulfur (S). Also the highest total N values were obtained from 50% pellet biochar treatment (13).

Amendment with biochar was shown to affect foliar PO43- and K+ in both species and N concentration in hydrangea. Concentration of these nutrients were higher in the biochar amended treatments. N concentration decreased in boxwood leaves in biochar treatments in compared to the control (Table. 3). The switchgrass biochar in this experiment was a source of K and P for the plants due to measurable differences in plants nutrient concentration caused by biochar amendment. A meta analysis of 114 published paper concluded that biochar addition to soils caused an increase in plant tissue potassium concentration but the concentration of plant tissue N and P doesn't show any significant effect of biochar (14).

Moving the nursery industry towards increased sustainability requires better management of irrigation. Developing management practices that make more efficient use of irrigation water is important for improving sustainability of nursery crop production. A precision irrigation system in combination with biochar, a readily available, low cost substrate amendment that increases water holding capacity reduced the water and nutrient leaching in hydrangea. This could help nursery growers who are trying to conserve water or expand production on existing and/or limited water supplies.

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Table 1. Nutrient release curve over four time periods. Leachate nitrate, phosphate, and potassium from a pinebark substrate amended with either 0, 10, or 25% switchgrass fertilized with slow release fertilizer. Values with the same letter in each plant and each nutrient were not significantly different (p = 0.05).

Plant	Biochar rate (%)	Time 1	2	3	4
		NO_3^- (mg)			
Hydrangea	0	1.75ab	2.87ab	1.75ab	1.25ab
Hydrangea	10	1.29ab	3.69a	2.18ab	1.41b
Hydrangea	25	1.91ab	1.9ab	4.3ab	2.01ab
Boxwood	0	1.29d	2.5cd	8.5ab	8.36bcd
Boxwood	10	9.55bcd	7.13abc	11.54ab	7.88bcd
Boxwood	25	6.08bcd	11.19ab	13.81ab	23.34a
		PO_4^{3-}(mg)			
Hydrangea	0	0.24bcd	0.31abcd	0.23cd	0.15d
Hydrangea	10	0.35abcd	0.65abcd	0.4abcd	0.38cd
Hydrangea	25	0. 76ab	0.72abc	0.89a	0.50abcd
Boxwood	0	0.07f	0.47ef	1.22d	1.65cd
Boxwood	10	1.69de	1.50d	1.89cd	1.2de
Boxwood	25	3.54bc	4.06b	3.63bc	5.9a
		K^+ (mg)			
Hydrangea	0	2.41c	2.84bc	1.64c	1.34c
Hydrangea	10	4.95c	10.31a	4.61abc	2.69bc
Hydrangea	25	7.46bc	9.32a	8.13a	5.64ab
Boxwood	0	3.82de	0.53f	13.04bcd	15.17abcd
Boxwood	10	24.28abc	16.78abcd	13.78bcde	18.55abcd
Boxwood	25	33.2ab	20.04e	6.90cde	69.26a

Table 2. Substrate nitrate, phosphorous and potassium concentration from a pinebark substrate amended with either 0, 10, or 25% switchgrass fertilized with slow release fertilizer. Values in same column with the same letter in each plant were not significantly different ($p = 0.05$).

Plant	Biochar rate (%)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	K^+ (mg/L)
Hydrangea	0	40.96b	5.97b	79.88a
Hydrangea	10	118.93a	8.6b	109.68a
Hydrangea	25	130.44a	14.81a	102.68a
Boxwood	0	51.9b	4.81c	60.7b
Boxwood	10	154.33a	9.67b	89.65b
Boxwood	25	161.29a	25.0a	164.0a

Table 3. Foliar nutrient concentrations of green velvet boxwood and pinky winky hardy hydrangea in a pinebark substrate amended with either 0, 10, or 25% switchgrass biochar. Values in same column with the same letter in each plant were not significantly different ($p = 0.05$).

Plant	Biochar rate (%)	N (%)	PO_4^{3-} (mg/L)	K^+ (mg/L)
Hydrangea	0	2.34b	2,795b	7,382b
Hydrangea	10	2.41ab	3,471a	8,882b
Hydrangea	25	2.64a	3,805a	11,119a
Boxwood	0	3.11a	2,347b	7,416b
Boxwood	10	2.84b	3,202a	8,506b
Boxwood	25	2.77b	3,770a	10,605a