Water Management

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Modeling Daily Water Use of Bedding Plants Based on Environmental Factors and Normalized Difference Vegetation Index

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Index Words  Petunia, irrigation, remote sensing, NDVI

Significance to Industry Efficient irrigation strategies allow greenhouse growers to reduce the amount of water used for production while maintaining plant quality. Additional benefits of improved irrigation strategies include reduced fertilizer input, fewer disease problems, and alleviated environmental pollution. Quantitative information on water requirements of bedding plants is essential for more efficient irrigation, yet remains limited. Applications of quantitative water use models in commercial settings can be difficult due to the complexity and high cost of estimating canopy size needed for the modeling. We used Petunia ‘Dreams Red’ (Petunia × hybrida) as a model crop to develop quantitative models that predict its daily water use (DWU) based on environmental factors and a remotely sensed canopy size index – normalized difference vegetation index (NDVI). Multiple linear regression models developed using reference evapotranspiration (ET0, calculated from environmental data) and NDVI were able to explain 93% of variation in DWU of Petunia ‘Dreams Red’, suggesting that NDVI can be a reliable proxy for plant size. Quantitative water use models developed using easily obtained NDVI and environmental data can be readily applied in production settings.

Nature of Work Plant water requirement, which is the amount of water needed to replenish water lost through evapotranspiration, changes on a daily basis driven by variations in environmental conditions as well as increases in plant size over time (1). While environmental parameters are relatively easy to measure, direct determination of plant size is often destructive and time consuming. Remote sensing of vegetation indices provides a continuous and non-destructive method to estimate canopy size for water use models. Studies have shown that normalized difference vegetation index (NDVI), which is calculated based on canopy reflectance in the red and near-infra red bands (2), correlates well with fractional light interception, percent canopy closure, leaf area index, and canopy productivity (3, 4, 5). Our objectives were to 1): determine the reliability of using NDVI data to track changes in plant sizes; 2): determine the feasibility of using NDVI in place of ‘crop coefficients’ (the ratio of crop DWU to reference evapotranspiration (ET0)) that are commonly used in agronomic applications; and 3): develop quantitative models that describe DWU of petunia ‘Dreams Red’ based on ET0 and NDVI. Seeds of petunia 'Dreams Red' were sown into round black plastic containers (6.5" diameter, 2.3 L volume) filled with a soilless substrate (Fafard 1P, 80% peat: 20% perlite (v/v); Sun Gro Horticulture, Agawam, MA). Controlled-release fertilizer (19-4-8; Harrell’s, Lakeland, FL) was incorporated into the substrate at a rate of 10 lbs/yd3 (~6 g/L). A
modified sensor-automated irrigation system developed by Nemali and van Iersel (6) was used to maintain substrate volumetric water content at 35% (v/v) and to quantify plant daily water use. Environmental factors, including light, temperature, relative humidity, vapor pressure deficit, and wind speed inside the greenhouse were measured every minute with the assistance of a datalogger (CR1000; Campbell Scientific, Logan, UT). Daily ET$_0$ was calculated from these environmental data (7).

A combination of one up-looking and multiple down-looking NDVI sensors (Decagon Devices, Pullman, WA) were used to measure incident radiation and light reflected by the canopy, respectively. Both sensors are essentially two-band radiometers that measure wavebands centered at 650 (red) and 810 nm (near infrared, NIR). NDVI was calculated as NDVI = (NIR-RED)/(NIR+RED), where NIR and RED are percent reflectance in the near infrared region and red region, respectively. Down-looking sensors were mounted so that each sensor had a downward field of view of a greenhouse bench area of 0.6 m$^2$, which contained 6 pots of petunia plants, which was treated as an experimental unit. NDVI were measured every 5 min from 11:00 am to 2:00 pm and then averaged to obtain daily averages.

The experimental design was a completely randomized design with four replications. Data were analyzed using linear, non-linear and multiple linear regressions using SigmaPlot (Systat Software, San Jose, CA).

**Results and Discussion** The automated irrigation system was able to maintain substrate water content close to the set point (35% WWC) throughout the study period. Daily water use of petunia ‘Dreams Red’ ranged from 5 to 160 ml/plant/day and tended to increase over time as plants grew bigger. A drop in DWU was typically observed on days with low ET$_0$ (Fig. 1).

NDVI increased linearly over time during vegetative growth, until canopy closure was nearly complete (Fig. 2). However, the red flowers of petunia ‘Dreams Red’ reflect light at the two wavebands of interest (i.e. red and near infrared) differently from green leaves, with substantially higher reflectance at the red band. As a result, NDVI declined gradually when flowers started to form and cover the leaves (Fig. 2). The crop coefficients, which were calculated as crop DWU per square meter of bench divided by reference evapotranspiration, increased linearly over time as plants grew. NDVI, however, increased asymptotically with increasing crop coefficient, indicating decreasing sensitivity of NDVI to increasing plant size. In addition to the decline in the measured NDVI caused by flowering observed in this study, NDVI measurements have decreased sensitivity to increases in plant size when crop leaf area index is high (4). Nevertheless, multiple linear regression models developed using ET$_0$ and NDVI were able to explain 93% of variation in DWU of petunia ‘Dreams Red’ (Fig. 3):

\[
\text{Predicted DWU} = -133 + 2176 \times \text{ET}_0 \times \text{NDVI} - 962 \times \text{NDVI} \quad (R^2 = 0.93)
\]
Our results demonstrate that remotely sensed NDVI can be used as a reliable proxy for plant size, especially during vegetative growth. Other plant size proxies, such as plant age and percent canopy closure, have been used to develop quantitative water use models for ornamental plants in earlier studies (8,9,10). However, certain drawbacks have limited their applications in production setting. For instance, the use of plant age as proxy for plant size is subjected to low model repeatability due to the inability to account for the influence of environmental variations on plant size among growing seasons (9). Percent canopy closure tracks changes in plant sizes well but is laborious to measure (10). NDVI provides a reliable, continuous, and non-destructive method to estimate canopy size. The use of NDVI, combined with easily obtained environmental data, allows for accurate prediction of plant daily water use and thus could improve the applicability of quantitative water use models in production settings.

**Literature Cited**

Figure 1. Reference evapotranspiration ($ET_0$) and daily water use (DWU) of petunia ‘Dreams Red’ over time. Note that DWU dropped on days with low $ET_0$ (e.g., day 59).
Figure 2. Daily average normalized difference vegetation index (NDVI) of petunia ‘Dreams Red’ over time. Regression line was fitted using data collected during vegetative growth.
Figure 3. Predicted versus measured daily water use (DWU) of petunia 'Dreams Red'. Models for predicting DWU was developed using reference evapotranspiration and normalized difference vegetation index.
A Simple Collection System for Routine Leaching Fraction Testing of Micro-Irrigated Container Crops

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Index Words Best management practice, irrigation efficiency

Significance to the Industry A leaching fraction (LF) test measures the amount of leachate that drains out of a container relative to the amount applied. When conducted routinely, LF testing can be used to monitor and adjust irrigation run times to minimize leaching and optimize irrigation efficiency. We describe a simple leachate collection system for routine measurement of LF in micro-irrigated, large containers. The collection system provides growers with a simple and reliable method for adopting LF testing as an irrigation best management practice.

Nature of Work Leaching fraction is the volume of container leachate (drainage) collected relative to the volume of irrigation water applied to the container. For routine LF testing, the method for measuring LF should be simple and require minimal labor and capital costs. Working with Saunders Brothers nursery (Piney River, VA), we found a simple leachate collection system that could be left in the field provided an economically effective means for routine LF testing (Million et al., 2015). We describe the leachate collection system and some considerations for its use.

Materials and Methods LF testing requires measurement of both the amount of container leachate and the amount of water applied to the container:

\[
LF\% = \frac{\text{amount of leachate}}{\text{amount of irrigation applied}} \times 100\%.
\]

A portable scale that weighs to the nearest 0.01kg is likely the fastest means of measuring both leachate and irrigation water.

The amount of container leachate can be measured using a simple leachate collection setup that we have found to be effective (Fig. 1). The container is placed on an aluminum pizza pan supported underneath by two 1-foot pieces of 4 inch x 4 inch lumber. A drill press with a ½-inch-diameter punch is used to create a drain hole at the edge of the pizza pan just inside the rim. A downward punch creates a small funnel that facilitates drainage through the hole. The elevated container and pizza pan allow leachate to drain into a collection tray (e.g. aluminum foil pan) placed underneath the drainage hole. If natural slope does not exist, we place a wood shim under the wood supports to create slope to direct container leachate toward the drain hole. When collecting leachate over multiple irrigation cycles, we place a cover over the collection tray to limit evaporation as well as
keep wind from moving the tray. When the test is complete, a cover such as shown in Fig. 1, can be used to store the tray in the field until the next test is conducted.

The amount of water applied to the container during a LF test can be determined by simply placing an emitter from an adjacent container into a collection pail. We typically place spray-stake emitters inside a section of PVC pipe to direct spray into the collection pail. When collecting irrigation water over multiple irrigation cycles, we place a cover over the collection pail to minimize evaporation.

Results of LF tests can be used to adjust irrigation run times to achieve a desired LF%:

\[
\text{Adjusted run time} = \frac{100\%-\text{measured LF}%}{100\%-\text{desired LF}[]} \times \text{test run time.}
\]

For example, if measured LF was 35% for 12 minutes of irrigation, then the adjusted run time to achieve a desired LF of 20% would be 9.8 minutes (65 ÷ 80 x 12 minutes).

**Discussion** The use of routine LF testing has proven to be a valuable tool for optimizing irrigation efficiency at container nurseries (Stanley, 2012). Labor costs associated with routine LF testing in both sprinkler and micro-irrigated container crops were reported by Million et al., 2015. The material cost of the pizza pan collection system described herein is about $10 ($8 for pizza pan). Add another $5-10 for a wooden structure to cover the collection tray. Using pizza pans and collection trays made of aluminum suggests that these components should have a very long and useful life in the nursery. The pizza pan collection system also lends itself for collecting pour-through leachate solutions for monitoring electrical conductivity (EC) and/or nutrient levels during production. The visual nature of the LF test combined with the low cost and ease of conducting routine LF testing should help growers adopt LF testing as a valuable tool for monitoring and guiding irrigation in the nursery.

**Literature Cited**

Figure 1. A simple leachate collection system can be left in the field for routine leachate fraction testing. A drainage hole punched just inside the rim of the aluminum pizza pan allows leachate to be collected in a tray.
Effect of Biochar on Nutrient Release and Retention in Container Crops

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Index Words Nitrate, phosphate, potassium, boxwood, hydrangea

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 (NO₃⁻), phosphate (PO₄³⁻) 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 cm³/cm³ and provided water until container capacity to determine the impact of biochar on water and nutrient leaching. Over the growing season the mass of NO₃⁻ and PO₄³⁻ 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 NO₃⁻ and PO₄³⁻ 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 PO₄³⁻ 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 \((\text{NO}_3^-)\), phosphate \((\text{PO}_4^{3-})\) and potassium \((\text{K}^+)\) 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 (ECOH-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 \((\theta)\) 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 cm³/cm³, slightly
greater than 0.20 cm³/cm³, 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 cm³/cm³. 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 (NO₃⁻), phosphate (PO₄³⁻), 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 cm³/cm³) was reached until near container capacity (0.41 cm³/cm³). 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. NO₃⁻ mass loss was not significantly different after increasing biochar amendment rate at individual time periods in hydrangea’s leachate, whereas NO₃⁻ 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 PO₄³⁻ 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 PO4- 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 PO4- 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.

**Literature Cited**


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).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Biochar rate (%)</th>
<th>Time</th>
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<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO$_3^-$ (mg)</td>
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<tr>
<td>Hydrangea</td>
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<td>6.08bcd</td>
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<td></td>
<td></td>
<td>PO$_4^{3-}$ (mg)</td>
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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).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Biochar rate (%)</th>
<th>NO$_3$ (mg/L)</th>
<th>PO$_4^{3-}$ (mg/L)</th>
<th>K$^+$ (mg/L)</th>
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<tr>
<td>Hydrangea</td>
<td>0</td>
<td>40.96b</td>
<td>5.97b</td>
<td>79.88a</td>
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<td>10</td>
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<td>161.29a</td>
<td>25.0a</td>
<td>164.0a</td>
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</table>

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).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Biochar rate (%)</th>
<th>N (%)</th>
<th>PO$_4^{3-}$ (mg/L)</th>
<th>K$^+$ (mg/L)</th>
</tr>
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<td>2.77b</td>
<td>3,770a</td>
<td>10,605a</td>
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